CHAPTER 3: THE WATER QUALITY AND FLUSHING CHARACTERISTICS OF THE PARKER RIVER-PLUM ISLAND SOUND ESTUARY

3.1 Overview

The original DMF monograph presented data on water quality and the type and degree of pollution which affect the marine environment within the study area. In the years subsequent to this report, there have been a number of water quality studies of the Sound. These include the Plum Island Sound Minibay Project, which analyzed the flushing characteristics and fecal coliform contamination while also obtaining some baseline measurements of nutrients. The Massachusetts Department of Environmental Protection (DEP) carried out several general water quality surveys through the Watershed Initiative.

3.2. Methods and Materials

3.21. 1968 Monograph

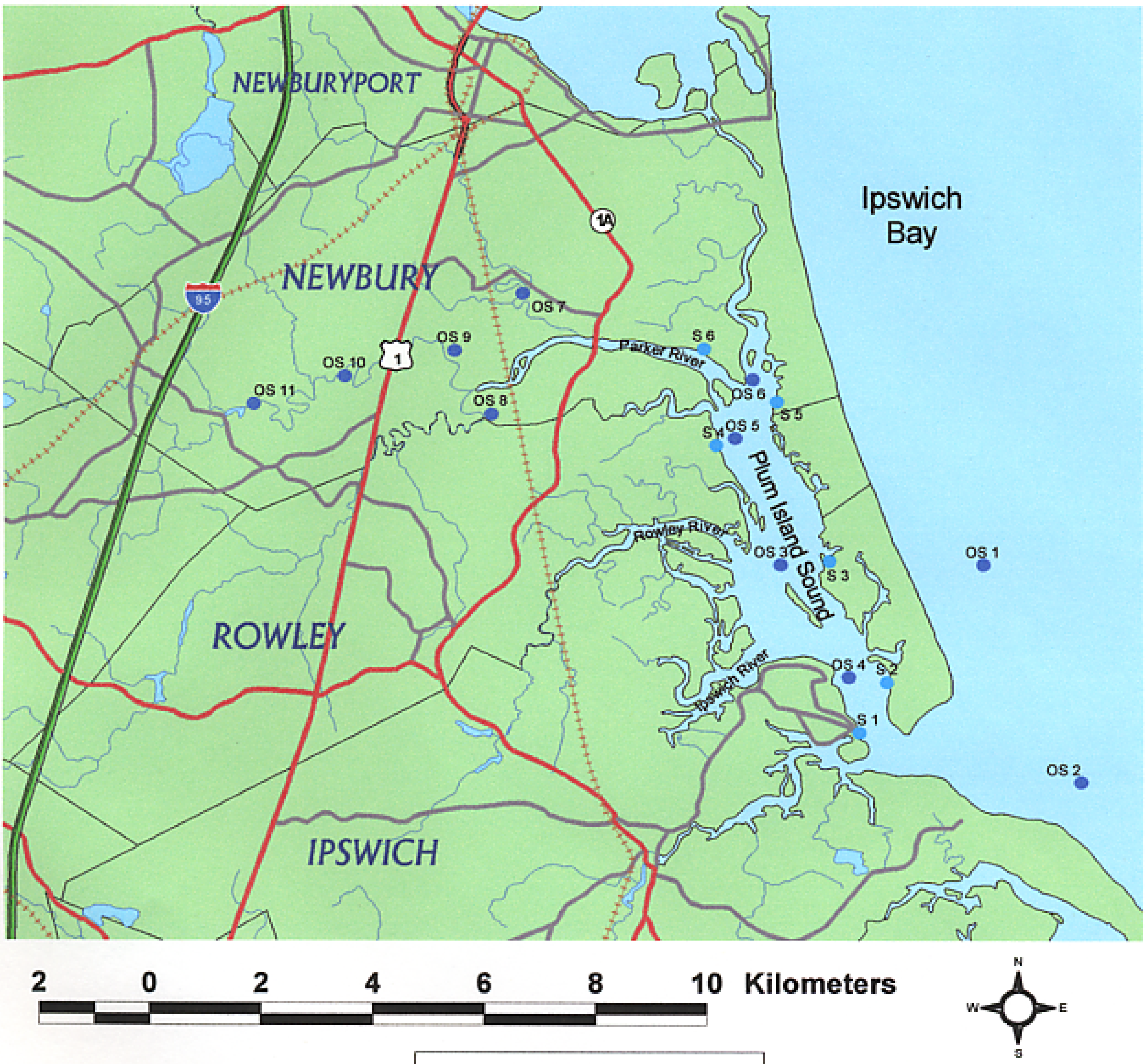
Six shore sampling stations were established at various locations along the shores of the study area, over a distance of six miles (Fig. 3.1a). These stations included Little Neck, S_1; Bluffs, S_2; Knobs, S_3; Nelson's Island, S_4; SubHeadquarters, S_5; and Newbury Town Landing, S_6. Sampling was conducted monthly from January through December 1965. More detailed descriptions of these sampling stations are in the chapter on fisheries resources.

Air and surface water temperatures and surface salinities were also recorded at three offshore stations set up primarily for monthly finfish sampling by the contract dragger *Peggybell* in the deep water portions of the estuary and adjacent areas. These stations were all within Ipswich: Camp Sea Haven, OS_1; Castle Neck, OS_2; and Middle Ground OS_3.

Supplementary surface water temperatures and salinity measurements were obtained during periodic offshore finfish sampling utilizing the shrimp trawl. Eight stations were sampled throughout the estuary from the lower portion of Plum Island Sound (Great Neck) to the head of the tidal portion of Parker River (Woolen Mill). These stations included Great Neck, OS_4; Nelson's Island, OS_5; Cape Merrill, OS_6; White's Bridge, OS_7; Mill River, OS_8; South Shore, OS_9; Thurlow's Bridge, OS_{10}; and the Woolen Mill, OS_{11} (Fig. 3.1a).

Colorimetric water chemistry kits were utilized in the field for water sampling. Hach Kit #CA-2 was used for dissolved oxygen, carbon dioxide and hydrogen ion (pH) determinations. Hach Kit #ABS-2 was used for determining detergent concentrations. Wide range salinity hydrometers, calibrated from 0-45 ppt, were used for surface salinity measurements. Pocket thermometers, calibrated in 2 ^{o} Fahrenheit (F) graduations, were used for taking air and surface

Fig. 3.1a. DMF Water Quality Stations

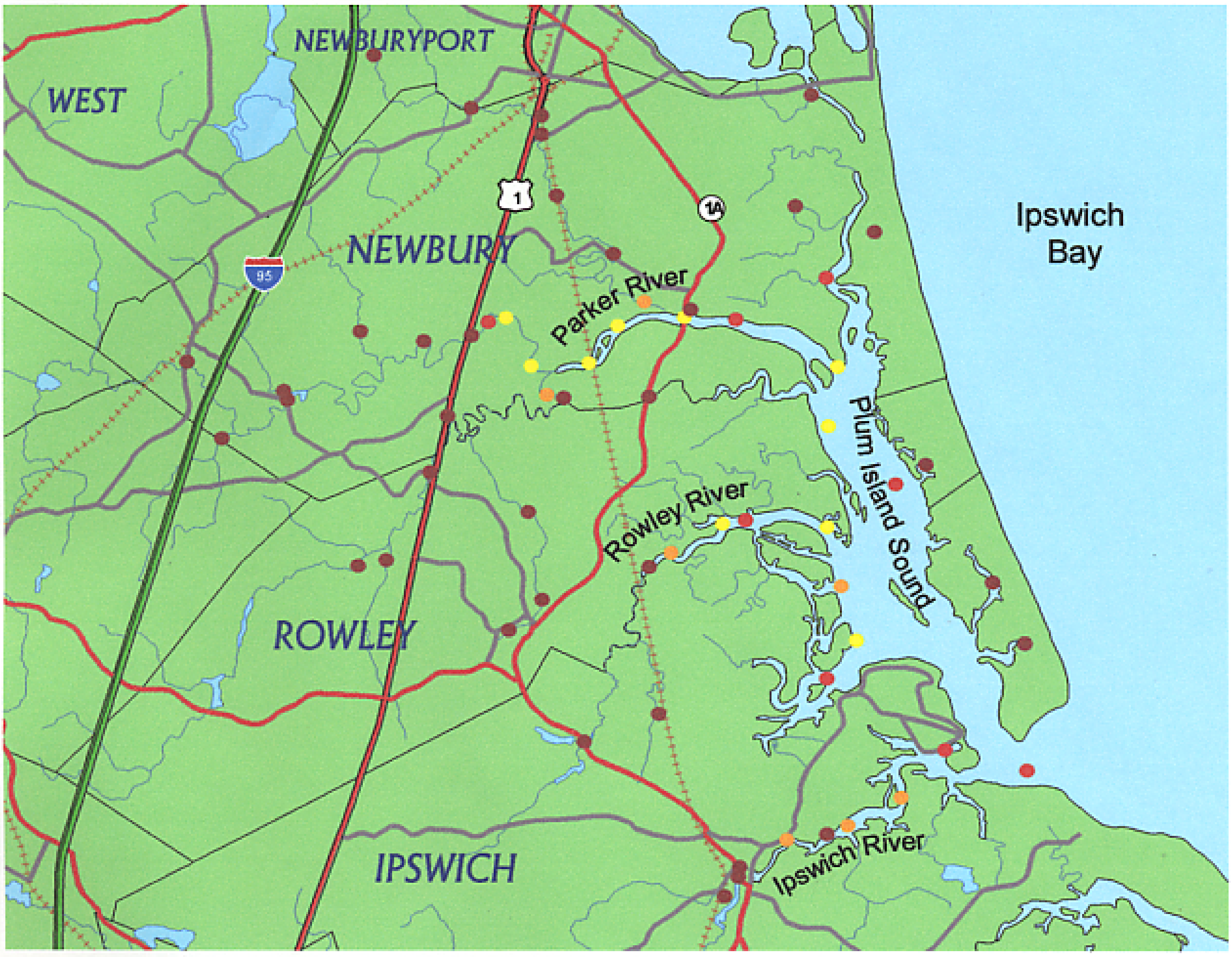


Legend

DMF Water Sampling Stations

- Off Shore
- Shoreline

Fig. 3.1b. MAS Water Quality Stations



2 0 2 4 6 8 10 Kilometers

N W E S

Legend

MAS Water Sampling Stations

- Boat 92 & 93 Fecal
- Boat 93
- Boat 93 Fecal
- Shore Fecal

water temperatures. A Secchi disc was used to determine water transparencies. Supplementary temperatures and salinities were recorded at eight additional offshore finfish sampling stations checked periodically in the shallower portions of the estuary.

3.22. Minibay Project

3.221 Salinity, Temperature, Dissolved Oxygen and Nutrients

Field sampling for these parameters in 1992 consisted of surveys of eight stations sampled both at low and at high tide (Fig. 3.1b). They are labeled in the text as MAS1, MAS2, etc. Data were collected for salinity, temperature, dissolved oxygen, nutrients, fecal coliforms and Secchi depth. A Sea Bird SBE-19 profiler was used to measure temperature, conductivity, depth and dissolved oxygen. Refer to the Minibay Project report for more details.

Water samples for nutrient analyses were collected at the same eight stations using a WILDCO horizontal sampler. At the shallower stations, a single sample was collected from 1 m depth, or at mid-depth if very shallow. At the two deeper stations, station 1 at the mouth of the Sound and station 12 in the middle of the Sound, two samples were taken, one at 1 m depth and one at 1 m above bottom. During each survey, two samples were collected at each of two stations as replicates.

Fifty milliliters of each sample was filtered through a glass fiber filter (Gelman A/E) into a bottle containing a premeasured volume of phenol solution to fix the sample for ammonium analysis. The filter was then folded, wrapped in labeled aluminum foil and placed in a desiccator for chlorophyll α analysis. The remaining sample was placed in a sterile 250 ml wide mouth bottle for fecal coliform analysis and two pre-cleaned 500 ml polyethylene bottles for analysis of other nutrients. The parameters measured and the methods used are indicated in Tables 3.1a and 3.1b.

Table 3.1a. Sampling conditions for the analytes measured during the water quality surveys.

Parameter	Matrix	Sampling Points*	Sampling Method	Holding Time h=hours d=days	Container Type**
ammonia	Filtered water	1992, 1993	Discrete sample	12 h	AG
nitrate + nitrite	whole water	1992, 1993	Discrete sample	12 h	P
total particulate nitrogen	whole water	1992, 1993	Discrete sample	12 h	P
total nitrogen	whole water	1992, 1993	Discrete sample	12 h	P
phosphate	whole water	1992, 1993	Discrete sample	48 h	P
total phosphorus	whole water	1992, 1993	Discrete sample	48 h	P
silicate	whole water	1992, 1993	Discrete sample	28 d	P
total particulate carbon	whole water	1992, 1993	Discrete sample	7d	P
chlorophyll *a*	filtered particles	1992, 1993	Discrete sample	30 d	F
fecal coliforms	whole water	1992, 1993	Discrete sample	6 h	P
salinity	whole water	vertical profile at each station	1992: Seacat 1993: STD-12	N/A	N/A
temperature	whole water	vertical profile at each station	1992: Seacat 1993: STD-12	N/A	N/A
dissolved oxygen	whole water	1992 only, vertical profile at each station	Seacat profiler	N/A	N/A

* 1992: Low and high tide, 1 per station, 2 depths at stations 1 and 12, replicates at 2 stations.
1993: Low tide only; nutrients at stations 1, 3, 12, 15; fecal coliforms at 15 stations.

** AG = Amber Glass; P = Polyethylene; F = Filter

Table 3.1b. Analytical conditions for the analytes measured during the water quality surveys.

Parameter	Method	Reference	Accuracy (µM)	Detection Limit (µM)
ammonia	phenol/hypochlorite (autoanalyzer)	Lambert and Oviatt, 1986	0.02 *	0.06**
nitrate + nitrite	Cd-Cu reduction / sulfanilamide / N-ED HCl_2	Lambert and Oviatt, 1986	0.01*	0.03**
total particulate nitrogen	elemental analyzer	Lambert and Oviatt, 1986	0.05	0.56
total nitrogen	persulfate oxidation / NO_3 analysis	Lambert and Oviatt, 1986	0.1-0.3*	0.3 - 0.9**
phosphate	molybdate/ascorbic acid	Lambert and Oviatt, 1986	0.01 *	0.03**
total phosphorus	persulfate oxidation / PO_4 analysis	Lambert and Oviatt, 1986	0.04*	0.12**
silicate	molybdate/ascorbic acid	Lambert and Oviatt, 1986	0.02*	0.06**
total particulate carbon	elemental analyzer	Lambert and Oviatt, 1986	0.5	0.6
chlorophyll *a*	acetone extraction/ fluorescence	Lambert and Oviatt, 1986	0.01 µg/L	0.01 µg/L
fecal coliforms	membrane filtration	APHA 1989	( )	( )
Conductivity	internal field electrode	Sea Bird Instruments (manual)	0.001 s/m	0 to 6.5 s/m (range)
temperature	thermistor	Sea Bird Instruments (manual)	0.01° C	-5 to 35° C (range)
dissolved oxygen	polarigraphic electrode	Sea Bird Instruments (manual)	0.15 mg/L	0 to 15 mg/L (range)

* Accuracy is equivalent to the standard deviation of the estimate for each analysis as reported in Lambert and Oviatt

** Detection threshold is defined as three times the standard deviation.

The sampling program was altered in 1993 to allow a more intensive sampling of salinity distribution to better evaluate the flushing characteristics of the Plum Island Sound system. This involved several changes: (1) a different salinity profiling instrument (2) more salinity profiling stations, and (3) fewer water chemistry stations. There were 21 standard stations in the 1993 program covering most of the same areas as in 1992, except for Plum Island River, with a greater density of sampling stations as well as extending sampling further up the Ipswich and Rowley Rivers (Figure 3.2b). Stations 1 through 21 are the standard sampling stations for these surveys. Stations 22 through 25 are additional stations that were sampled at low tide on most surveys for salinity and fecal coliforms. Hydrographic measurements were taken at each station at low and high tide. An Applied Microsystems Model STD-12 was used to sample the salinity and temperature profiles. Sampling intervals were set at 0.1 m for all surveys.

Water sampling for nutrient analyses was considerably reduced in 1993. The 1992 data provided a good basis for evaluating nutrient levels in the Sound/rivers system, but a few stations were sampled in 1993 to provide a basis for evaluating differences between years. Only four stations were sampled, at the surface, and only at low tide. These were stations 1, 3, 12 and 15. Sample handling and analysis were the same as for 1992.

To prevent this document from becoming too lengthy, our data presentation includes only those stations from the Minibay project that are near or at DMF stations. For information on the additional stations, the reader should examine the report from that project.

3.222 Flushing Characteristics

Streamflow data - For carrying out flushing time analyses, freshwater input rates are required. The primary sources of freshwater to the Plum Island Sound system are the Ipswich and Parker Rivers, both of which are gauged by the U.S. Geological Survey (USGS). Streamflow data were provided by USGS for 1992 and 1993 (through November) for the Ipswich River gauge near Ipswich (Station 01102000) and the Parker River gauge at Byfield (station 01101000). The locations of these gauges are shown in Figure 3.3. These stations only measure flows resulting from 80% of the drainage area to the Ipswich River and 36% of the area draining to the Parker River, and it does not account for other areas such as those draining to the Rowley River, the Eagle Hill River and directly to the Sound. In 1992, these additional areas were to be accounted for by scaling areas from USGS gauge readings.

The Ipswich and Parker River USGS stream gauges were used for calculating total streamflow to each subarea of Plum Island Sound. These represented the greatest area of drainage by far, and a more stable basis for calculating fresh water sources than measurements of flow from the smaller drainage subbasins. Values have been standardized by drainage basin area to calculate a volume flow rate per area.

Estimation of Flushing Times - Flushing time calculations were carried out using an estuarine box model called BayModel developed at Applied Science Associates, Inc. A separate set of such values were produced for each survey day.

A box model previously developed for Narragansett Bay (Swanson and Jayko, 1988) was used to calculate flushing times in Plum Island Sound. The model is based on the box model approach presented by Officer (1980). In a box model, the region under consideration is segmented into a number of boxes in which the physical characteristics are approximately uniform. Each box can have either one or two layers in the vertical. Mean, tidally-averaged values are used for all input parameters and the exchange coefficients and concentrations calculated by the model are, likewise, time-invariant solutions.

Officer's (1980) box model methodology was developed for estuarine application. The primary forcing mechanisms for mean estuarine circulation are river flow and horizontal and vertical salinity gradients. The box model of Swanson and Jayko (1988) extends the

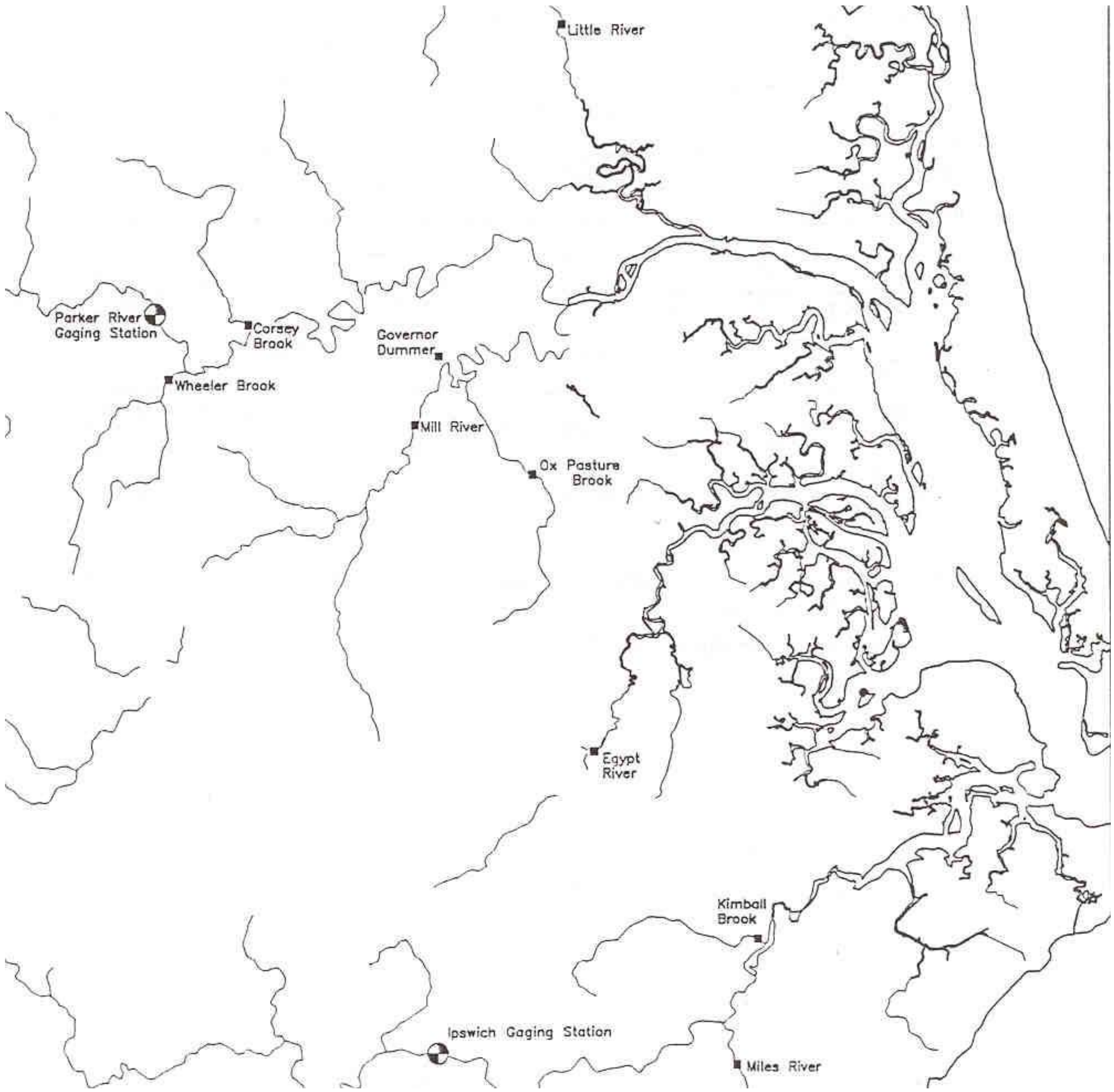


Figure 3.2. Location of USGS stream flow gauging stations on the Ipswich and Parker Rivers.

methodology presented by Officer to represent three dimensions by allowing each box to have four vertical faces through which flow may enter or leave, in addition to two layers in the vertical.

Observed values of salinity and river flow are used to determine the hydrodynamic exchange coefficients. All exchanges occur at the boundaries of the boxes. The vertical boundaries should enclose regions of similar properties. The horizontal boundary between upper and lower layers, where used, is placed at the halocline.

The model can also be used to calculate constituent (e.g., total nutrient) concentrations in each box. The conservation of constituent mass equation, with allowances for flux input and/or output (decay and settling of the constituent) is solved for each box. The calculated concentrations represent a steady state condition determined by the river (freshwater) flow, salinity, and constituent (e.g., nutrient) loading.

The flushing time of each box is determined using the fraction of freshwater method (Mills et al., 1984). With the estuary divided into boxes, the flushing time may be calculated:

$$t = \sum \frac{f_i V_i}{R_i}$$

This equation says that the flushing time for the system is the sum of the flushing times for each box, expressed as the volume of freshwater in the box, $f_i V_i$, divided by the river flow through the box R_i. The fraction of freshwater, f_i, is given by

$$f_i = \frac{S_o - S_i}{S_o}$$

in which S_o is the local ocean salinity. The flushing time of a dissolved constituent discharged at any point into the estuary can be computed by summing the flushing times of each of the boxes seaward of the discharge.

3.223. Fecal Coliforms Studies

In the Minibay Project water samples for fecal coliform analysis were collected in 1992 and 1993 from stations sampled by boat throughout Plum Island Sound and the estuarine reaches of the Parker River, the Rowley River and the Ipswich River (Fig. 3.1b). This two year sampling effort was done in conjunction with the flushing and nutrient studies described above. Because the results from the two years of sampling by boat indicated that the major sources of fecal coliform to the Sound were upstream, a program of shoreline sampling was initiated throughout the tributary rivers of the Sound in late 1992 and continued through 1995. The bacterial concentrations found at these stations, combined with flow measurements estimated from the size of the drainage basin, were used to estimate loadings of bacteria to the Sound from different sources.

Water samples were collected in pre-sterilized, pre-labeled 250 ml polyethylene bottles from both boat and shoreline sites. Samples were taken according to EPA standard procedures for collecting, handling, and analyzing water for microbes. Water samples were analyzed using the mTEC method (Dufour et al. 1981, US EPA 1985). All laboratory analyses were carried out at Massachusetts Audubon's Norman's Woe Marine Laboratory. See Buchsbaum et al. (1996) for further details.

Sampling for the Minibay Project was designed with two goals. The first was to identify particular "hot spots", i.e., areas with particularly high concentrations of fecal coliforms. This was carried out by repeatedly sampling a variety of marine and freshwater stations throughout the Plum Island Sound watershed. The second goal was to calculate the relative loads of fecal coliforms from different subwatersheds. We selected one station from each subwatershed for intensive sampling and combined the information from fecal coliform tests and with estimates of flow volume (from basin area and streamflow measurements - see ASA Report, Section A) to calculate loadings.

The Minibay project intercalibrated their bacterial sampling with those from the shellfish sanitation program of DMF. Some samples were split roughly in half and analyzed both by MAS and DMF. This gave us an estimate of the comparability of the mTEC method with the most probable number (MPN) procedures used by DMF.

Sampling events were divided into those occurring during dry and wet weather, since precipitation typically has a profound influence on fecal coliform concentrations in coastal waters. Rainfall was measured at the Ipswich Wastewater Treatment Facility and provided to the Massachusetts Audubon by Timothy Henry. The categorization of sampling events as either rain or dry is somewhat arbitrary, since the amount, timing, and longevity of any bacterial pulse from a storm event will be affected by the size, gradient, and other physical characteristics of the drainage basin. A sampling day was considered as a rain event if it had rained greater than 0.5 inches within the previous 36 hours or greater than 1.0 inch within the previous 84 hours. This definition of a wet weather event is less conservative than that used by DMF's shellfish sanitation program for Plum Island Sound. DMF closes shellfish beds for 5 days after a rainfall of greater than 0.5 inches and for 8 days after a rainfall of over 1 inch. The Massachusetts Water Resources Authority's Harbor Studies Program defines a rainfall event in Boston Harbor as greater than 0.3 inches of rain the previous two days (A. Rex, pers. comm.).

3.3. Results and Discussion of Water Quality Analysis

3.31. Dissolved Oxygen and Transparency

The DMF study indicated that Plum Island Sound did not have a low dissolved oxygen (DO) problem in 1965 (see Tables 3.2-3.7 and 3.12). Of the six shoreline stations sampled by DMF in 1965, four never had DO lower than 10.0 mg/L even in midsummer when DO concentrations are often somewhat depressed in coastal waters. The lowest DO recorded by DMF, 7.0 mg/L at Nelson's Island in July, was still above the Massachusetts water quality standard of 6.0 for marine waters. Depressed dissolved oxygen concentrations are not unusual for an organically-rich salt marsh area in mid summer. The measurements of DO in the Minibay project in 1992 were slightly lower than that of DMF (Tables 3.13-3.18), but in most cases were still above the state standard and therefore not indicative of low DO problems. Several samples from the Town Landing and Route 1 stations on the Parker River, however, were below the state standard of 6.0 (Tables 3.13-3.18). Although water quality could have declined between 1965 and 1992 due to increased nutrient loading, the difference between the two studies could also be attributed to differences in analytical methods (Winkler titrations on a grab sample versus a continuous measurement with the Seabird Seacat Profiler) or to normal variations. The samples collected by the Minibay Project were an integration of DO concentrations at all depths by the Seabird profiler, whereas those collected by DMF were from a discrete surface sample. Normal variability cannot be ruled out either, since marsh creeks are naturally high in organic matter in the summer. As is described in the fisheries section, the 1965 survey was carried out during a time of relative drought when less land-based organic matter and nutrients would have been washed into the upper portions of the Sound, hence higher DO concentrations were likely under oceanic influence in those years.

The Massachusetts Department of Environmental Protection carried out a water quality survey in 1989 of Ipswich and Essex Bays. Their sampling stations included some in the lower part of Plum Island Sound and in the Ipswich River estuary (Tables 3.19-3.21). Their results support the idea that dissolved oxygen levels in the Sound itself are generally high and close to saturation even during the summer months. Like the Minibay Project, however, dissolved oxygen levels in some of their "upstream" stations were occasionally below the state standard (data not shown, refer to Mass DEP 1989). There may be an issue with organic matter or nutrient loading at these sites.

The more open areas of the southern part of the Sound had the highest transparency, generally in excess of 5 m even in midsummer. Water transparency depths varied from greater than 5 m to less than 2 m. According to the DMF data, two stations relatively upstream from the mouth of the Sound, the Nelson's Island station and the station on the Parker River at the Newbury town landing, were more turbid than those closer to the mouth.

3.32. Temperature and Salinity

Surface water temperatures recorded at the six shore stations from January through December 1965 varied from a low of -1^{o}C to a high of 26^{o}C (Tables 3.2-3.8). Recorded surface water temperatures seldom exceeded 21^{o}C at the shore stations during 1965. The highest surface water temperatures recorded at Little Neck and the Bluffs, located in the lower portion of the estuary were 16^{o}C and 18^{o}C, respectively. The range of values for the three offshore stations sampled throughout the year, which were also in the lower part of the estuary, was 2-19^{o}C (Tables 3.9-3.11).

Surface water temperatures taken at the eight shrimp trawl stations sampled during the period from May 13 to September 24, 1965 ranged from 12^{o} to 22^{o}C and surface salinities from 0 to 31.0 ppt (Table 3.12). Five of the eight offshore shrimp trawl stations had recorded surface water temperatures of 22^{o}C in September.

Minimum and maximum surface salinity measurements recorded at the six shore stations ranged from 21.0 to 33.5 ppt in 1965 (Table 3.8). The maximum salinity fluctuation recorded at any one station occurred at Newbury Town Landing (21.0 to 31.0 ppt), located approximately 8 miles from the mouth of Plum Island Sound.

Jerome et al. (1968) reported that the freshwater discharge from the Parker River-Plum Island Sound watershed had relatively little dilution effect on the ocean waters within the estuary compared to other Massachusetts estuaries. This resulted in a more uniform, relatively high salinity environment in Plum Island Sound and in much of the tidal portion of Parker River.

The Minibay Project also found a considerable range of freshwater dilution of seawater upstream over the course of the 1992 and 1993 seasons particularly at the more upstream stations (Tables 3.13-3.18). In April 1992, the Parker River was almost totally fresh at low tide. In August and September on the other hand, there was relatively little dilution of the seawater until well up the Parker River at station MAS21. Results for June and December lay between these extremes.

Salinities were generally higher at comparable sampling stations during the DMF study compared to the Minibay project. Salinity data from the two studies suggest that the period of the DMF study was one of lower freshwater inputs and lower rainfall. Salinity differences were also apparent between the two years of the Minibay project. Salinities tended to be higher in 1993 than in 1992 (Tables 3.13-3.18) suggesting that 1993 was a drier year. In the September survey 1993, salinity remained above 26 ppt at low tide. During the 1992 surveys, the upstream stations showed lower salinities than this even at high tide.

Table 3.2. Water Analysis Data Collected at the Little Neck Shore Station (S1), 1965.

Date	Tidal Stage	Temperature (F) Water	Air	Salinity (ppt)	pH	Dissolved Oxygen (ppm)	Carbon Dioxide (pprn)	Deter-gent (ppm)	Trans-parency (feet)
Jan 6	Low +2 1/2 (hrs)	34	46	30.0	8.0	>10.0	10.0	0.1	>15
Feb 11	High +4	31	41	32.5	8.0	>10.0	5.0	0.1	>15
March 9	Low +3 1/2	38	*40*	23.0	8.0	10.0	10.0	0.1	>15
May 18	Low +2	56	54	26.0	8.0	10.0	*5.0*	0.1	15
June 1	High +1	56	74	31.0	8.0	10.0	*5.0*	0.0	>15
July 12	High	56	78	30.0	8.0	>10.0	*5.0*	0.1	>15
Aug 26	High +1	58	62	30.0	8.0	>10.0	*5.0*	0.1	>15
Sept 22	High +2 1/2	61	93	31.0	8.0	>10.0	*5.0*	0.1	>15
Oct 14	Low +4	54	57	32.0	8.0	>10.0	*5.0*	0.1	>15
Nov 15	Low +1	44	39	33.5	8.0	>10.0	*5.0*	0.1	>15
Dec 15	Low +2	40	34	31.0	8.0	>10.0	*5.0*	0.1	>15

Table 3.3. Water Analysis Data Collected at the Bluffs Shore Station (S2), 1965.

Date	Tidal Stage	Temperature (F) Water	Air	Salinity (ppt)	Dissolved Oxygen pH	Carbon Dioxide (ppm)	Deter-gent (ppm)	Trans-parency (feet)
March 15	High +1 (hr)	36	44	31.0	8.0	5.0	0.1	-
April 28	High + 1 1/2	44	57	26.0	8.5	5.0	0.1	15+
May 18	Low +5	52	57	25.0	8.0	5.0	0.1	15
June 1	High +11/2	56	68	30.5	8.0	0.0	0.1	15+
July 15	High +1	56	81	29.0	8.5	0.0	0.1	15+
Aug 25	High +1	58	87	31.5	8.0	0.0	0.0	-
Sept 23	High + 1/2 64	74	32.0	8.0	5.0	0.2	15+	
Oct 15	Low +2	56	63	28.0	8.0	5.0	0.1	15+
Nov 16	Low +3	48	51	32.0	8.0	5.0	0.2	15+
Dec 16	Low +3	40	42	31.0	8.0	5.0	0.3	-

Table 3.4. Water Analysis Data Collected at the Knobs Shore Station (S3), 1965.

Date	Tidal Stage	Temperature (F) Water	Air	Salinity (ppt)	pH	Dissolved Oxygen (ppm)	Carbon Dioxide (ppm)	Deter-gent (ppm)	Trans-parency (feet)
March 16	High +4 1/2 (hrs)	40	42	29.5	8.5	>10.0	5.0	0.1	-
April 28	High +21/2	47	58	27.0	8.5	>10.0	5.0	0.1	>15
May 21	Low +3	59	59	29.0	8.0	>10.0	10.0	0.1	>15
June 14	High	54	52	30.0	8.0	10.0	5.0	0.0	>15
July 13	High +2	64	80	30.0	8.5	>10.0	0.0	0.1	>15
Aug 25	High	60	80	31.0	8.0	>10.0	0.0	0.1	-
Sept 22	High	72	88	28.5	8.0	10.0	5.0	0.1	>15
Oct 15	Low +1	53	63	31.5	8.0	>10.0	5.0	0.1	>15
Nov 16	Low +31/2	46	51	31.0	8.0	>10.0	5.0	0.2	>15
Dec 15	Low +5	37	36	30.5	8.0	>10.0	5.0	0.2	>15

Table 3.5. Water Analysis Data Collected at the Nelson's Island Shore Station, 1965.

Date	Tidal Stage	Temperature (F) Water	Air	Salinity (ppt)	pH	Dissolved Oxygen (ppm)	Carbon Dioxide (ppm)	Deter-gent (ppm)	Trans-parency (feet)
Jan 6	Low +4 (hrs)	30	40	28.0	8.0	>10.0	10.0	0.1	6
March 15	High +5	40	37	32.5	8.0	>10.0	5.0	0.1	3
April 27	Low +3	48	45	24.5	7.5	>10.0	5.0	0.1	>15
May 18	Low +4	57	55	25.0	7.5	9.0	5.0	0.1	-
June 14	Low +31/262	58	23.0	8.0	9.0	10.0	0.1	5	
July 13	Low +31/273	74	26.5	8.0	7.0	5.0	0.1	8	
Aug 27	High + 1	66	76	30.0	8.0	9.0	10.0	0.0	5
Sept 22	High +31/2	68	92	31.0	8.0	>10.0	5.0	0.1	7
Oct 14	Low +3	54	59	32.5	7.0	>10.0	10.0	0.1	>15
Nov 15	Low +21/244	41	32.0	8.0	>10.0	10.0	0.1	>15	
Dec 15	Low +3	34	36	29.0	8.0	>10.0	5.0	0.1	10

Table 3.6. Water Analysis Data Collected* at *the Sub-Headquarters Shore Station (S5), 1965.

Date	Tidal Stage	Temperature (F) Water	Air	Salinity (ppt)	pH	Dissolved Oxygen (ppm)	Carbon Dioxide (ppm)	Deter-gent (ppm)	Trans-parency (f-t)
Jan 26	High +4 (hrs)	30	34	31.5	8.0	10.0	10.0	0.2	-
Feb 9	Low +31/230	35	28.0	8.0	>10.0	10.0	0.2	-	
March 25	Low	40	58	24.0	8.0	10.0	10.0	0.1	>15
April 28	High +5	52	58	25.0	8.0	>10.0	5.0	0.1	>15
May 21	Low +4	66	64	24.0	8.0	10.0	10.0	0.1	>15
June 14	High +1	62	52	29.0	8.0	>10.0	10.0	0.1	10
July 12	High +3	69	72	31.0	8.0	>10.0	5.0	0.1	>15
Aug 25	High	66	78	30.0	8.0	>10.0	10.0	0.1	-
Sept 24	Low +4	70	74	28.0	7.5	10.0	5.0	0.1	-
Oct 15	Low +3112,	56	63	30.0	8.0	>10.0	5.0	0.1	10
Nov 16	Low +4	46	50	31.0	8.0	>10.0	5.0	0.2	>15
Dec 16	Low +4	38	40	29.0	8.0	>10.0	5.0	0.2	-

Table 3.7. Water Analysis Data Collected at the Town Landing Shore Station (S6), 1965.

Date	Time of Day	Tidal Stage	Temperature (F) Water	Air	Salinity (ppt)	pH	Dissolved Oxygen (ppm)	Carbon Dioxide (ppm)	Deter-gent (PP-)	Trans-parency (feet)
Jan 6	1:30 P.M.	High	30	42	27.5	8.0	>10.0	10.0	0.1	8
Feb 9	11:00 A.M.	Low	30	37	21.0	7.0	>10.0	10.0	0.1	-
March 15	11:30 A.M.	High +21/2 (Hrs)	36	41	27.0	8.0	>10.0	5.0	0.1	7
April 27	10:45 A.M.	High +346	47	21.0	8.0	>10.0	5.0	0.2	7	
May 17	11:40 A.M.	Low +5	58	60	26.5	8.0	8.0	5.0	0.1	6
June 1	12:10 P.M.	High	62	70	27.0	8.0	8.0	5.0	0.1	5
July 13	10:00 A.M.	Low +5	72	84	26.0	8.0	10.0	5.0	0.1	>15
Augt 26	1:15 P.M.	High +3	66	64	30.0	8.0	8.0	10.0	0.1	-
Sept 22	8:45 A.M.	High +1/2	60	76	29.0	8.0	9.0	10.0	0.1	>15
Octr 14	10:25 A.M.	Low +2	58	58	28.0	7.5	>10.0	10.0	0.1	8
Nover 15	1:45 P.M.	Low +4	44	41	31.0	8.0	>10.0	10.0	0.1	>15
Decer 15	1 1:00 A.M.	Low +1	36	34	29.0	8.0	10.0+	10.0	0.1	5

Table 3.8. Ranges for Temperature and Water Analysis Measurements for the shoreline stations in the Parker River-Plum Island Sound Estuary, 1965.

Sampling Station	Temperature (F) Water Min	Water Max	Air Min	Air Max	Salinity (ppt) Min	Max	Ave	pH Min	Max	Ave	Diss. Oxygen (mg/L) Min	Max	Ave	Carbon Dioxide (ppm) Min	Max	Ave	Detergent (ppm) Min	Max	Ave
Little Neck	31	61	34	93	23.0	33.5	28.2	8.0	8.5	8.0	10.0	10.0	10.0	5.0	10.0	5.8	0.0	0.2	0.1
Bluffs	36	64	42	87	25.0	32.0	29.6	8.0	8.5	8.1	10.0	10.0	10.0	0.0	5.0	3.9	0.0	0.3	0.1
Knobs	37	72	36	88	27.0	31.5	29.8	8.0	8.5	8.2	10.0	10.0	10.0	0.0	10.0	4.5	0.0	0.2	0.1
Nelson's Island	30	73	36	92	23.0	32.5	28.5	7.5	8.0	7.9	7.0	10.0	9.5	5.0	10.0	7.2	0.0	0.1	0.1
Sub-Headquarters	30	70	34	78	24.0	31.5	28.4	7.5	8.0	8.0	10.0	10.0	10.0	5.0	10.0	7.5	0.1	0.2	0.1
Town Landing	30	72	34	84	21.0	31.0	26.8	7.0	8.0	7.9	8.0	10.0	9.4	5.0	10.0	7.9	0.1	0.2	0.1

Table 3.9. Water Analysis Data Collected at the Camp Sea Haven Offshore Station (OS1), 1965.

Date	Tidal Stage	Temp (ºF) Water	Air	Salinity (ppt)
Jan 6	Low +3 (hrs)	36	37	32.5
March 3	High	36	42	29.0
April 21	Low +3	42	48	28.0
May 26	High +4	-	-	30.0
June 28	High +2	56	78	30.0
Aug 25	High +2	59	68	-
Sept 28	Low +2	54	50	32.0
Oct 13	Low +*5*	50	56	-
Nov 26	Low +*5*	44	48	33.0
Dec 8	High +21/2	38	35	31.5

Table 3.10. Water Analysis Data Collected at the Castle Neck Offshore Station (OS2), 1965.

Date	Tidal Stage	Temperature (F) Water	Air	Salinity (ppt)
January 6	Low +5 (hrs)	37	40	32.5
March 3	High + 1	36	52	30.5
April 21	Low +4	44	56	29.0
May 26	High +3	-	-	29.0
June 28	Low +4 1/2	54	72	31.0
Aug 25	High + 1	60	66	-
Sept 28	Low +5	54	56	31.0
Oct 13	High +1 1/2	50	56	-
Nov 26	High + I/2	44	46	32.5
Dec 8	High + 1 1/2,	40	33	32.0

Table 3.11. Water Analysis Data Collected at the Middle Ground Offshore Station (OS3), 1965.

Date	Tidal Stage	Temperature (F) Water	Air	Salinity (ppt)
January 6	High +1 (hr)	36	40	32.5
April 21	High	42	*50*	-
May 26	High +2	-	-	28.5
June 28	High + 1/2	54	74	30.5
August 25	High + ½	66	70	-
September 28	High + 1/2	54	57	31.0
October 13High + 1/2	*50*	52	-	
November 26	High +1	44	48	32.0
December 8	High	40	28	32.5

Table 3.12. Water Analysis Data Collected at the Eight Shrimp Trawl Stations (OS4-OS11), 1965.

Station	Date	Tidal Stage	Water Temperature (F)	Salinity (ppt)
Great Neck	June 29	High + 1 (hr)	54	30.0
	September 23	High +3 1/2	63	31.0
Nelson's Island	June 29	High +2	66	30.0
	September 23	High +4 1/2	72	29.0
Cape Merrill	May 28	High +3	66	26.0
	June 28	High +3 1/2	-	30.0
	September 23	High +5	72	28.5
White's Bridge	May 14	High +2 1/2	60	24.0
	May 28	High +2 1/2	67	20.0
Mill River	May 14	High + 1/2	60	20.0
	June 30	Low +51/272	20.0	
South Shore	May 14	High	60	22.0
	June 30	High + ½	62	21.0
Thurlow's Bridge	May 13	High +21/2	64	10.0
	June 30	High + 1/2	66	20.0
	September 24	High +2 1/2	72	-
Woolen Mill	May 13	High + 1 1/2	66	0.0
	September 24	High + 1 1/2	72	-

Table 3.13. Salinity, temperature, and dissolved oxygen (DO) data at the mouth of the Sound off Steep Hill (MAS1), 1992 and 1993. DO was not measured in 1993. This station is between DMF's S1 (Little Neck Shore Station) and OS 2 (Castle Neck Offshore Station). Data from Plum Island Sound Minibay Project.

Survey	Date	Instrument	Tide	Depth (m)	Temperature ©-	Salinity (ppt)	Oxygen (mg/L)
1992-1	04/28/92	SEACAT	High	9.5	6.15	28.63	9.55
1992-1	04/28/92	SEACAT	Low	6.2	8.12	25.08	11.05
1992-2	06/11/92	SEACAT	High	9.6	13.17	28.82	8.18
1992-2	06/11/92	SEACAT	Low	7.8	15.10	27.25	8.87
1992-3	08/26/92	SEACAT	High	12.3	16.43	30.50	7.13
1992-4	09/25/92	SEACAT	High	13.0	11.88	30.67	8.22
1992-4	09/25/92	SEACAT	Low	1.3	14.73	30.57	7.19
1992-5	12/16/92	SEACAT	High	6.8	5.01	31.58	9.50
1992-5	12/16/92	SEACAT	Low	6.9	2.84	28.38	9.36
1993-1	06/03/93	STD-12	High	6.9	8.97	30.29	
1993-1	06/03/93	STD-12	Low	3.6	11.84	29.72	
1993-2	07/07/93	STD-12	High	6.2	14.54	30.78	
1993-2	07/09/93	STD-12	Low	4.6	18.82	30.78	
1993-3	08/04/93	STD-12	High	8.4	15.12	30.95	
1993-3	08/04/93	STD-12	Low	3.9	19.73	30.36	
1993-4	09/08/93	STD-12	High	6.4	15.18	30.53	
1993-4	09/08/93	STD-12	Low	3.8	17.29	30.95	
1993-5	11/19/93	STD-12	Low	2.6	7.71	29.05	
1993-5	12/02/93	STD-12	High	3.8	6.31	30.61	

Table 3.14. Salinity, temperature, and dissolved oxygen (DO) data at the Ipswich River station at Little Neck (MAS2), 1992 and 1993. DO was not measured in 1993. No equivalent DMF station. Data from Plum Island Sound Minibay Project.

Survey	Date	Instrument	Tide	Depth (m)	Temperature ©-	Salinity (ppt)	Oxygen (mg/L)
1992-1	04/28/92	SEACAT	High	3.9	6.16	28.71	9.04
1992-1	04/28/92	SEACAT	Low	2.3	10.81	13.42	8.99
1992-2	06/11/92	SEACAT	High	4.6	13.77	27.46	7.22
1992-2	06/11/92	SEACAT	Low	2.7	18.12	18.63	8.15
1992-3	08/26/92	SEACAT	High	3.7	16.96	30.12	6.76
1992-4	09/25/92	SEACAT	High	3.9	11.86	30.58	8.37
1992-4	09/25/92	SEACAT	Low	6.9	12.69	27.28	8.86
1992-5	12/16/92	SEACAT	High	2.2	4.88	31.38	9.47
1992-5	12/16/92	SEACAT	Low	0.8	1.33	13.15	11.09
1993-1	06/03/93	STD-12	High	2.6	9.90	29.97	
1993-1	06/03/93	STD-12	Low	2.0	14.54	24.24	
1993-2	07/07/93	STD-12	High	2.0	15.55	30.71	
1993-2	07/09/93	STD-12	Low	1.3	21.03	29.40	
1993-3	08/04/93	STD-12	High	3.1	16.38	30.87	
1993-3	08/04/93	STD-12	Low	1.1	19.82	28.82	
1993-4	09/08/93	STD-12	High	1.8	15.75	30.57	
1993-4	09/08/93	STD-12	Low	1.4	18.51	29.96	
1993-5	11/19/93	STD-12	Low	1.7	7.12	19.27	
1993-5	12/02/93	STD-12	High	2.7	5.85	30.00	

Table 3.15. Salinity, temperature, and dissolved oxygen (DO) data in the center of Plum Island Sound near Can 23 (MAS12), 1992 and 1993. DO was not measured in 1993. MAS12 is between DMF's OS3 and OS5 (Middle Ground and Nelson's Island Offshore Stations). Data from Plum Island Sound Minibay Project.

Survey	Date	Instrument	Tide	Depth (m)	Temperature ©	Salinity (ppt)	Oxygen (mg/L)
1992-1	04/28/92	SEACAT	High	5.6	7.60	24.44	9.48
1992-1	04/28/92	SEACAT	Low	2.9	10.64	16.87	9.84
1992-2	06/11/92	SEACAT	High	4.3	14.38	27.46	7.78
1992-2	06/11/92	SEACAT	Low	4.1	19.14	22.17	7.01
1992-3	08/26/92	SEACAT	High	5.4	16.78	30.45	7.03
1992-4	09/25/92	SEACAT	High	3.5	11.83	30.40	8.23
1992-4	09/25/92	SEACAT	Low	1.0	14.81	29.50	7.39
1992-5	12/16/92	SEACAT	High	2.0	4.78	31.26	9.43
1993-1	06/03/93	STD-12	High	4.7	13.01	28.35	
1993-1	06/03/93	STD-12	Low	3.9	14.78	26.15	
1993-2	07/07/93	STD-12	High	5.3	17.08	30.81	
1993-2	07/09/93	STD-12	Low	3.4	24.70	30.24	
1993-3	08/04/93	STD-12	High	6.5	16.63	30.87	
1993-3	08/04/93	STD-12	Low	3.7	23.25	30.64	
1993-4	09/08/93	STD-12	High	6.1	16.77	30.77	
1993-4	09/08/93	STD-12	Low	4.0	20.42	30.61	
1993-5	11/19/93	STD-12	Low	2.4	7.76	27.20	
1993-5	12/02/93	STD-12	High	4.5	6.05	30.43	

Table 3.16. Salinity, temperature, and dissolved oxygen (DO) data in the Parker River near the Newbury Town Landing (MAS15), 1992 and 1993. DO not measured in 1993. This station is equivalent to DMF's S6 (Newbury Town Landing). Data from Plum Island Sound Minibay Project.

Survey	Date	Instrument	Tide	Depth (m)	Temperature ©	Salinity (ppt)	Oxygen (mg/L)
1992-1	04/28/92	SEACAT	High	3.9	9.25	19.00	9.43
1992-1	04/28/92	SEACAT	Low	1.0	11.44	0.22	8.95
1992-2	06/11/92	SEACAT	Low	1.9	20.50	10.12	5.49
1992-3	08/26/92	SEACAT	High	2.9	22.09	27.51	5.71
1992-4	09/25/92	SEACAT	High	2.6	13.55	30.35	7.98
1992-4	09/25/92	SEACAT	Low	1.4	15.75	25.33	6.52
1992-5	12/16/92	SEACAT	High	0.9	2.04	26.35	10.15
1993-1	06/03/93	STD-12	High	1.3	14.28	25.91	
1993-2	07/07/93	STD-12	High	4.4	22.63	30.44	
1993-2	07/09/93	STD-12	Low	1.9	25.74	27.67	
1993-3	08/04/93	STD-12	High	4.5	22.64	30.80	
1993-3	08/04/93	STD-12	Low	2.1	24.14	29.18	
1993-4	09/08/93	STD-12	High	4.1	19.72	30.62	
1993-4	09/08/93	STD-12	Low	2.2	21.98	29.88	
1993-5	11/19/93	STD-12	Low	0.4	8.02	22.27	
1993-5	12/02/93	STD-12	High	3.0	4.03	26.94	

Table 3.17. Salinity, temperature, and dissolved oxygen (DO) data in the Parker River at Route 1 (MAS21), 1992 and 1993. DO not measured in 1993. This station is near DMF's OS9 (South Shore). Data from Plum Island Sound Minibay Project.

Survey	Date	Instrument	Tide	Depth (m)	Temperature ©	Salinity (ppt)	Oxygen (mg/L)
1992-1	04/28/92	SEACAT	High	5.1	10.18	2.96	8.64
1992-1	04/28/92	SEACAT	Low	0.7	11.47	0.13	8.32
1992-2	06/11/92	SEACAT	Low	5.5	20.81	4.29	5.87
1992-3	08/26/92	SEACAT	High	4.7	23.47	15.83	4.31
1992-4	09/25/92	SEACAT	High	4.0	16.02	23.93	5.77
1992-4	09/25/92	SEACAT	Low	1.8	16.38	10.95	7.00
1992-5	12/16/92	SEACAT	High	2.3	0.17	12.09	11.37
1992-5	12/16/92	SEACAT	Low	1.3		0.98	12.73
1993-1	06/03/93	STD-12	High	4.0	15.43	12.73	
1993-2	07/07/93	STD-12	High	5.5	24.60	26.39	
1993-2	07/09/93	STD-12	Low	3.2	26.11	14.15	
1993-3	08/04/93	STD-12	High	5.8	24.85	28.74	
1993-3	08/04/93	STD-12	Low	3.5	24.76	21.53	
1993-4	09/08/93	STD-12	High	5.5	22.24	29.14	
1993-4	09/08/93	STD-12	Low	3.7	22.64	25.93	
1993-5	11/19/93	STD-12	Low	3.1	7.40	7.19	
1993-5	12/02/93	STD-12	High	5.1	3.54	14.79	

Table 3.18. Ranges for temperature, salinity, and dissolved oxygen (DO) for the Parker River-Plum Island Sound Estuary, 1992-3. Compare with Table 3.12. Data from Plum Island Sound Minibay Project.

	Temp		Salinity (ppt)			Dissolved Oxygen (mg/L)		
Station	min	max	min	max	ave	min	max	ave
Steep Hill	2.84	19.73	25.08	31.58	29.76	7.13	11.05	8.78
Little Neck	1.33	21.03	13.15	31.38	26.55	6.76	11.09	8.66
Mid Sound	4.78	24.70	16.87	31.16	28.26	7.01	9.84	8.27
Town Landing	2.04	25.74	0.22	30.80	24.54	5.49	10.15	7.75
Parker at Rte 1	0.17	26.11	0.13	29.14	14.11	4.31	12.73	8.00

Table 3.19. Temperature, salinity, and dissolved oxygen concentrations from the mouth of Plum Island Sound in 1989 from a Massachusetts Department of Environmental Protection survey (station IP10). This station is at DMF's OS2 (Castle Neck Offshore Station and near MAS1 (Steep Hill). Samples were taken at an ebbing tide at 1 m depths intervals. Since there were only minor differences between different depths, only the results of samples collected at the depth closest to the surface (0.5 or 1 m) are shown. All measurements were made in situ with a Hydrolab Surveyor II (model SVR2) except 8/01 which was with a model 33 YSI SCT meter.

Date	Temperature (^oC)	Salinity (ppt)	Dissolved Oxygen (mg/L)
5/30/89	11.0	28.2	10.2
5/31/89	10.4	29.2	10.0
7/31/89	18.6	30.2	8.2
8/01/89	19.5	25.0	8.4
8/28/89	16.9	30.2	8.9
8/29/89	15.8	30.4	8.4

Table 3.20. Temperature, salinity, and dissolved oxygen (DO) from the Ipswich River at Little Neck in 1989 (DEP's IP07 station). This station is near MAS2. See Table 3.20 for details.

Date	Temperature (^oC)	Salinity (ppt)	Dissolved Oxygen (mg/L)
5/30/89	11.3	28.6	9.7
5/31/89	11.2	28.9	9.8
7/31/89	19.2	30.0	8.2
8/01/89	20.0	2405	8.4
8/28/89	17.2	30.2	8.4
8/29/89	18.4	29.6	7.5

Table 3.21. Temperature, salinity, and dissolved oxygen from Plum Island Sound off Great Neck in 1989 (DEP's IP09 station). This station is at DMF's Great Neck Offshore Station (DMF OS4). See Table 3.20 for details.

Date	Temperature (^oC)	Salinity (ppt)	Dissolved Oxygen (mg/L)
5/30/89	11.4	28.3	10.1
5/31/89	10.3	29.3	10.1
7/31/89	19.7	30.0	7.9
8/01/89	20.0	25.0	8.5
8/28/89	16.9	30.2	8.2
8/29/89	16.1	30.6	8.7

3.33 Nutrients

Results of the nutrient analyses for water samples collected during the 1992 and 1993 surveys conducted by the Minibay Project indicate a substantial range of values varying over the season and among different sample stations (Tables 3.22-3.29). Phosphate, for instance, appears to have a pattern of increasing upstream concentrations in June and August, but less obviously so or not at all during the other three surveys. Silicate routinely shows increasing upstream concentrations, most obviously for the Parker River. Nitrate plus nitrite, and to a lesser degree ammonia, show similar patterns to silicate, but are less consistent.

Total nitrogen and total phosphorus show similar increases in concentration with distance from the mouth of the Sound on all but the December survey. The ratio between the two varies somewhat from one survey to the next. Particulate carbon and particulate nitrogen also show comparable patterns of distribution over all surveys and retain a relatively uniform ratio of one to the other. The patterns from one survey to the next may vary, such that during some surveys (e.g., April) there are no conspicuous sources of particulates and during others, one or another of the rivers may be high (e.g., the Parker in June and September; the Ipswich in December).

Chlorophyll α distribution patterns resembled those of particulates more than any other constituent. Concentrations ranged over several orders of magnitude and varied more among different sample days than among individual stations on the same date. On June 11, 1992, chlorophyll α concentrations were between 9 and 32 ug/L whereas on December 16, 1992, all stations were less than 0.1 ug/L. Chlorophyll α levels in 1993 were similar to those in 1992, except that there were no very high or very low days. As a basis for comparison, chlorophyll α range from about 2-3 ug/L in the open waters of Massachusetts Bay (MWRA Contingency Plan, February 1997). According to NOAA, "normal [algal] blooms become problematic when chlorophyll α values reach 20 ug/L" (MWRA, 1997). Thus the chlorophyll α values in parts of Plum Island Sound occasionally exceeded a level that might stimulate eutrophication, at least in 1992.

Generally, replicate measurements of the same samples were very good (see report of the Minibay project). Poor replication appears to result from either of two conditions: (1) measurement of low concentration near the detection limit of the analysis, or (2) measurement of particle-related parameters. Ammonia is an analyte that was frequently found at low concentrations relative to its detection level. Thus, small variations between replicates appear as large relative changes. Ammonia is also very sensitive to contamination. Chlorophyll α and particulate carbon and nitrogen, are all particle related. Variation between replicates for such parameters is most likely largely driven by the natural variation in particle concentration in seawater ("patchiness") and is not so much due to sampling or analytical error.

As with chlorophyll, none of the nutrients measured in 1993 indicates any departure from the patterns seen in 1992. Given the ranges of values seen in 1992 and the relatively small sample number in 1993, only a large consistent shift in any variable would be evident as a change in conditions.

Table 3.22. Nutrient concentrations from the Steep Hill sampling station (MAS1), 1992 and 1993.

DATE	TIDE	DEPTH (m)	CHL_A (ug/L)	NH4 (uM)	NO2+ NO3 (uM)	TOTAL N (uM)	TOTAL P (uM)	DIP (uM)	PART. C (uM)	PART. N (uM)	SILICA (uM)	PART. C (mg/L)	PART. N (mg/L)
04/28/92	High	1	0.50	1.03	1.63	27.35	0.65	0.44	36.05	4.53	14.97	0.43	0.063
04/28/92	High	6	1.46	1.81	1.89	25.69	0.52	0.36	27.79	2.78	14.50	0.33	0.039
04/28/92	Low	1	2.33	1.09	0.72	29.75	0.78	0.23	35.92	4.68	31.31	0.43	0.066
04/28/92	Low	6	2.03	1.21	1.27	31.86	0.78	0.20	36.89	4.59	14.52	0.44	0.064
06/11/92	High	1	11.96	0.23	0.87	10.51	0.56	0.33	24.45	1.81	5.53	0.29	0.025
06/11/92	High	5	11.49	0.17	0.60	9.90	0.43	0.14	21.43	1.87	4.14	0.26	0.026
06/11/92	Low	1	18.76	0.31	0.22	10.87	0.51	0.09	13.05	1.71	6.81	0.16	0.024
06/11/92	Low	4	10.32	0.56	0.31	12.90	0.85	0.01	15.68	1.84	7.21	0.19	0.026
08/26/92	High	1	2.12	0.07	0.11	8.36	0.69	0.07	12.64	1.41	3.60	0.15	0.020
08/26/92	High	5	0.89	0.07	0.14	8.88	0.89	0.10	16.34	2.47	4.37	0.20	0.035
09/25/92	High	1	2.54	0.01	0.22	9.47	0.41	0.31	22.94	3.95	5.97	0.28	0.055
09/25/92	High	4	2.67	0.66	0.11	9.94	0.41	0.18	17.87	3.19	6.01	0.21	0.045
09/25/92	Low	1	1.30	3.49	1.71	22.27	0.70	0.68	36.71	4.07	25.83	0.44	0.057
09/25/92	Low	4	1.58	0.72	0.22	14.02	0.56	0.41	39.06	5.37	5.97	0.47	0.075
12/16/92	High	1	0.02	0.68	7.65	22.07	2.44	0.80	127.29	15.01	11.31	1.53	0.210
12/16/92	High	5	0.04	0.68	7.42	17.95	1.53	0.63	111.31	12.44	12.94	1.34	0.174
12/16/92	Low	1	0.02	1.00	7.55	19.23	1.24	0.52	44.68	3.10	20.41	0.54	0.043
12/16/92	Low	4	0.02	1.03	7.63	19.82	1.21	0.50	50.72	6.45	21.94	0.61	0.090
06/03/93	Low	1	3.08	0.50	0.10	22.10	0.40	0.02	9.25	1.14	3.50	0.11	0.016
07/07/93	Low	1	2.50	0.20	0.10	20.00	0.80	0.02	18.17	2.64	43.30	0.22	0.037
08/04/93	Low	1	3.33	0.20	0.30	30.60	0.40	0.18	26.67	3.71	17.90	0.32	0.052
09/08/93	Low	1	2.75	0.60	0.50	16.20	0.80	0.39	30.33	3.57	5.60	0.36	0.050
11/19/93	Low	1	2.42	1.60	1.20	22.80	0.40	0.02	25.75	3.14	24.10	0.31	0.044

Table 3.23. Nutrient concentrations at the Ipswich River station (MAS2 in 1992, MAS3 in 1993), 1992-1993.

DATE	TIDE	DEPTH (m)	CHL_A (µg/L)	NH4 (µM)	NO2 + NO3 (µM)	TOTAL N (µM)	TOTAL P (µM)	DIP (µM)	PART. C (µM)	PART. N (µM)	SILICA (µM)	PART. C (mg/L)	PART. N (mg/L)
04/28/92	High	1	0.88	0.38	1.02	26.66	1.20	0.46	38.93	3.51	12.27	0.47	0.049
04/28/92	Low	1	2.10	2.96	3.11	39.78	0.91	0.49	24.67	3.35	35.48	0.30	0.047
06/11/92	High	1	9.26	0.54	1.07	11.70	0.65	0.16	20.80	1.46	7.62	0.25	0.020
06/11/92	Low	1	9.85	1.91	1.60	24.22	0.77	0.22	21.09	2.25	34.74	0.25	0.032
08/26/92	High	1	1.44	0.22	0.22	8.75	1.23	0.13	14.03	2.05	5.61	0.17	0.029
09/25/92	High	1	3.08	0.81	0.46	10.81	0.41	0.33	27.81	4.27	7.02	0.33	0.060
09/25/92	Low	1	1.99	2.14	0.75	28.63	0.73	0.78	55.53	7.29	17.97	0.67	0.102
12/16/92	High	1	0.02	0.83	7.78	36.29	4.24	0.66	155.72	11.29	12.76	1.87	0.158
12/16/92	Low	1	0.02	2.22	13.19	40.11	2.47	0.84	110.05	9.77	81.91	1.32	0.137
06/03/93	Low	0.5	2.75	2.20	8.40	32.20	0.40	0.18	13.00	0.93	40.20	0.16	0.013
07/07/93	Low	0.5	3.00	1.80	0.20	39.30	0.40	0.02	19.92	2.86	8.20	0.24	0.040
08/04/93	Low	0.5	2.08	1.10	1.70	19.70	1.70	1.05	22.17	2.14	11.60	0.27	0.030
09/08/93	Low	0.5	3.00	4.30	1.20	29.70	1.20	0.90	28.75	3.79	15.10	0.35	0.053
11/19/93	Low	1	1.83	2.90	1.60	26.20	1.80	1.48	26.92	2.00	136.80	0.32	0.028

Table 3.24. Nutrient concentrations at Rowley River sampling station (MAS9), 1992-1993.

DATE	TIDE	DEPTH (m)	CHL_A (ug/L)	NH4 (µM)	NO2+ NO3 (µM)	TOTAL N (µM)	TOTAL P (µM)	DIP (µM)	PART. C (µM)	PART. N (µM)	SILICA (µM)	PART. C (mg/L)	PART. N (mg/L)
04/28/92	High	1	2.10	0.30	1.20	31.40	1.56	0.36	40.74	5.85	14.27	0.49	0.082
04/28/92	Low	0.5	2.36	2.90	3.23	44.51	0.71	0.28	34.84	4.49	41.14	0.42	0.063
06/11/92	High	1	14.30	0.62	1.06	17.83	0.82	0.17	15.73	2.15	12.33	0.19	0.030
06/11/92	Low	0.5	28.84	2.45	1.80	28.78	1.10	0.13	23.84	2.40	23.75	0.29	0.034
08/26/92	High	1	1.85	0.34	0.20	10.59	1.15	0.16	21.71	4.31	6.33	0.26	0.060
09/25/92	High	1	3.01	0.29	0.30	10.36	0.40	0.36	28.57	5.67	5.86	0.34	0.079
09/25/92	Low	0.5	2.12	1.78	0.57	21.64	0.91	0.39	53.34	7.37	8.20	0.64	0.103
12/16/92	High	1	0.03	1.15	7.49	20.87	1.45	0.83	30.57	4.93	17.73	0.37	0.069
12/16/92	Low	0.5	0.02	1.38	6.35	23.59	0.97	0.22	22.55	3.88	39.64	0.27	0.054

Table 3.25. Nutrient concentrations in the middle of Plum Island Sound near Can 23 (MAS12), 1992-1993.

DATE	TIDE	DEPTH (m)	CHL_A (ug/L)	NH4 (µM)	NO2+ NO3 (µM)	TOTAL N (µM)	TOTAL P (µM)	DIP (µM)	PART. C (µM)	PART. N (µM)	SILICA (µM)	PART. C (mg/L)	PART. N (mg/L)
04/28/92	High	1	2.60	0.42	1.46	29.19	0.88	0.41	33.73	4.36	14.10	0.40	0.061
04/28/92	High	5	1.48	0.06	1.41	30.18	0.91	0.41	37.00	4.74	14.06	0.44	0.066
04/28/92	Low	1	3.59	2.60	3.01	38.56	0.39	0.33	39.81	5.43	22.35	0.48	0.076
04/28/92	Low	4	1.55	2.78	3.03	36.13	0.52	0.28	40.16	5.47	41.48	0.48	0.077
06/11/92	High	1	12.66	0.51	0.76	13.94	0.90	0.38	15.93	1.80	8.11	0.19	0.025
06/11/92	High	4	14.77	0.45	0.58	11.65	0.43	0.12	9.86	1.22	6.53	0.12	0.017
06/11/92	Low	1	28.14	1.58	1.48	22.27	1.41	0.27	18.49	2.72	18.87	0.22	0.038
06/11/92	Low	4	24.15	1.18	1.42	21.44	0.88	0.38	18.17	2.32	18.00	0.22	0.033
08/26/92	High	1	0.89	0.01	0.14	8.49	0.89	0.07	13.78	1.99	3.73	0.17	0.028
08/26/92	High	4	1.30	0.16	0.12	8.15	0.53	0.05	11.32	1.07	4.24	0.14	0.015
09/25/92	High	1	3.08	0.25	0.54	10.58	0.46	0.31	26.71	4.95	6.05	0.32	0.069
09/25/92	High	4	4.04	0.16	0.39	10.69	0.48	0.36	31.69	5.48	5.97	0.38	0.077
09/25/92	Low	1	2.67	1.29	1.96	25.33	1.55	0.61	41.22	5.40	12.82	0.49	0.076
09/25/92	Low	4	1.71	1.66	0.61	21.11	1.01	0.49	36.53	4.73	8.71	0.44	0.066
12/16/92	High	1	0.04	0.77	7.67	20.05	1.91	0.69	37.33	6.79	12.51	0.45	0.095
12/16/92	High	4	0.04	0.77	7.74	20.27	1.75	0.66	14.30	4.27	13.62	0.17	0.060
12/16/92	Low	1	0.02	1.53	6.12	24.48	1.34	0.28	53.88	6.45	34.39	0.65	0.090
12/16/92	Low	4	0.03	2.20	6.10	25.79	1.58	0.25	61.65	6.10	36.71	0.74	0.085
06/03/93	Low	1	4.83	0.70	0.20	26.60	0.20	0.08	13.83	1.64	6.50	0.17	0.023
07/07/93	Low	1	3.67	0.60	1.90	22.10	1.30	0.29	20.08	2.43	9.30	0.24	0.034
08/04/93	Low	1	4.58	0.60	0.10	28.20	0.80	0.59	27.58	4.43	11.40	0.33	0.062
09/08/93	Low	1	4.67	1.30	1.60	26.40	1.60	1.00	30.17	3.29	9.80	0.36	0.046
11/19/93	Low	1	2.25	2.90	1.50	27.20	0.50	0.10	27.17	3.50	28.00	0.33	0.049

Table 3.26. Nutrient concentrations at the Parker River by the Newbury Old Town Landing (MAS15), 1992-1993.

DATE	TIDE	DEPTH (m)	CHL_A (ug/L)	NH4 (µM)	NO2+ NO3 (µM)	TOTAL N (µM)	TOTAL P (µM)	DIP (µM)	PART. C (µM)	PART. N (µM)	SILICA (µM)	PART. C (mg/L)	PART. N (mg/L)
04/28/92	High	1	2.09	3.62	2.40	37.42	1.62	0.38	29.61	4.40	20.59	0.36	0.062
04/28/92	Low	0.5	1.26	4.89	5.78	41.26	0.97	0.62	35.51	4.53	39.25	0.43	0.063
06/11/92	High	1	19.46	1.21	1.20	22.48	0.96	0.21	23.59	3.47	15.72	0.28	0.049
06/11/92	Low	0.5	16.88	5.62	4.00	37.20	1.26	0.47	29.79	3.66	46.05	0.36	0.051
08/26/92	High	1	4.86	0.10	0.16	18.83	1.51	0.29	27.98	3.93	5.61	0.34	0.055
09/25/92	High	1	2.40	1.16	0.11	15.06	0.54	0.14	35.57	6.14	2.81	0.43	0.086
09/25/92	Low	1	1.71	3.49	2.79	31.93	1.92	0.84	32.86	4.63	21.84	0.39	0.065
12/16/92	High	1	0.02	1.30	6.10	30.33	0.99	0.30	30.61	6.01	23.61	0.37	0.084
12/16/92	Low	1	0.01	1.79	8.56	31.92	1.32	0.32	28.50	5.83	73.32	0.34	0.082
06/03/93	Low	1	5.92	0.80	0.90	20.80	0.30	0.10	14.50	1.07	13.80	0.17	0.015
07/07/93	Low	1	2.42	1.40	0.90	36.20	1.80	0.51	24.75	2.79	17.00	0.30	0.039
08/04/93	Low	1	4.42	0.50	0.70	37.80	0.80	0.45	29.58	3.64	27.50	0.36	0.051
09/08/93	Low	1	4.42	12.30	1.20	41.60	2.40	2.01	32.83	3.93	25.10	0.39	0.055
11/19/93	Low	1	1.25	5.10	1.30	39.80	0.80	0.34	31.42	4.64	57.70	0.38	0.065

Table 3.27. Nutrient concentrations at the Parker River at Route 1 (MAS21), 1992.

DATE	TIDE	DEPTH (m)	CHL_A (ug/L)	NH4 (µM)	NO2+ NO3 (µM)	TOTAL N (µM)	TOTAL P (µM)	DIP (µM)	PART. C (µM)	PART. N (µM)	SILICA (µM)	PART. C (mg/L)	PART. N (mg/L)
04/28/92	High	1	1.13	2.26	6.73	45.16	0.97	0.18	43.51	5.64	50.63	0.52	0.079
04/28/92	Low	1	2.78	1.03	7.12	46.37	0.91	0.44	28.32	3.90	41.99	0.34	0.055
06/11/92	High	1	18.06	4.53	4.02	37.95	1.44	0.64	31.44	3.88	56.11	0.38	0.054
06/11/92	Low	1	22.51	1.04	3.95	44.29	1.01	0.56	85.31	12.14	66.79	1.02	0.170
08/26/92	High	1	10.35	3.11	2.34	41.13	2.48	1.01	35.44	3.62	33.95	0.43	0.051
09/25/92	High	1	4.32	4.56	3.58	35.17	0.85	0.10	60.45	7.26	31.11	0.73	0.102
09/25/92	Low	1	13.29	0.34	2.08	46.27	1.76	0.29	85.68	12.00	66.63	1.03	0.168
12/16/92	High	1	0.01	2.15	10.20	25.17	1.69	0.47	27.29	5.89	77.41	0.33	0.082
12/16/92	Low	1	0.01	1.94	15.17	35.79	1.26	0.50	33.44	4.03	133.39	0.40	0.056

Table 3.28. Nutrient concentrations at the Eagle Hill River (MAS22), 1992.

DATE	TIDE	DEPTH (m)	CHL_A (ug/L)	NH4 (µM)	NO2+ NO3 (µM)	TOTAL N (µM)	TOTAL P (µM)	DIP (µM)	PART. C (µM)	PART. N (µM)	SILICA (µM)	PART. C (mg/L)	PART. N (mg/L)
04/28/92	High	1	1.59	0.45	1.09	27.48	1.56	0.51	35.35	4.18	12.11	0.42	0.058
04/28/92	Low	0.5	3.31	1.69	0.90	37.57	0.97	0.13	49.06	5.81	33.42	0.59	0.081
06/11/92	High	1	11.49	0.34	1.09	12.47	0.53	0.09	9.07	1.02	7.84	0.11	0.014
06/11/92	Low	0.5	31.89	0.70	0.76	22.41	1.04	0.12	13.11	1.56	14.51	0.16	0.022
08/26/92	High	1	1.64	0.23	0.14	9.16	1.27	0.12	13.42	1.55	4.56	0.16	0.022
09/25/92	High	1	3.36	0.31	0.30	10.42	0.39	0.36	31.13	6.62	6.32	0.37	0.093
09/25/92	Low	0.5	2.12	2.40	0.82	27.47	0.81	0.70	59.39	7.17	15.85	0.71	0.100
12/16/92	High	1	0.04	1.30	7.65	21.60	2.54	0.73	53.53	5.43	13.09	0.64	0.076
12/16/92	Low	0.5	0.04	2.23	5.49	26.10	1.50	0.17	102.58	8.86	34.48	1.23	0.124

Table 3.29. Nutrient concentrations in the Plum Island River at Jericho Creek (MAS23), 1992.

DATE	TIDE	DEPTH (m)	CHL_A (ug/L)	NH4 (µM)	NO2+ NO3 (µM)	TOTAL N (µM)	TOTAL P (µM)	DIP (µM)	PART. C (µM)	PART. N (µM)	SILICA (µM)	PART. C (mg/L)	PART. N (mg/L)
04/28/92	High	1	1.42	4.80	4.90	39.62	0.91	0.59	36.51	4.83	29.65	0.44	0.068
04/28/92	Low	1	2.05	7.85	6.02	51.58	2.11	0.64	40.35	4.89	39.22	0.48	0.068
06/11/92	High	1	11.96	6.28	3.27	30.04	1.17	0.61	26.45	2.61	33.49	0.32	0.036
06/11/92	Low	0.5	38.69	7.18	6.55	40.80	1.62	0.75	28.86	4.16	46.71	0.35	0.058
08/26/92	High	1	5.96	0.34	0.26	24.17	1.83	0.68	43.90	5.25	10.17	0.53	0.074
09/25/92	High	1	2.88	2.36	0.42	19.91	0.59	0.32	32.21	5.61	6.17	0.39	0.079
09/25/92	Low	1	2.12	0.75	0.07	11.54	0.55	0.41	32.44	4.81	7.16	0.39	0.067
12/16/92	High	1	0.03	2.00	6.00	27.24	1.29	0.29	64.54	8.32	38.26	0.77	0.116
12/16/92	Low	1	0.01	3.85	6.63	29.97	1.07	0.33	35.80	4.41	48.65	0.43	0.062

Nutrient sampling was also carried out by the Massachusetts Department of Environmental Protection (DEP) during their 1989 water quality survey of the Ipswich and Essex estuaries. Practically all their total Kjeldahl nitrogen, ammonia, and nitrate measurements were below the levels of analytic detection (<0.9, <0.1, and <0.73 mg/L respectively) for three sample stations that were near or at MAS1, MAS2, and DMF's OS4. The lower detection limits makes it difficult to compare DEP and Minibay data for nitrogen. Chlorophyll α concentrations measured by DEP in 1989 are similar to those measured by the Minibay project at the same time of the year (Table 3.30).

Table 3.30. Chlorophyll* α *concentrations (mg/L) in selected stations sampled by DEP in 1989.

Station	7/31/89	8/1/89	8/28/89	8/29/89
IP10 (=MAS1)		2.21		
IP07 (=MAS2)	2.91		1.28	
IP09 (=DMF's OS4)	2.32		1.74	2.41

Additional nutrient data is currently being collected by the Plum Island Sound Long Term Ecological Research project coordinated by The Ecosystems Center, Woods Hole, MA. Those data are posted on their web site, http://ecosystems.mbl.edu.

3.34 Flushing Characteristics

3.341. Measurements of Freshwater Inputs

Figure 3.3 illustrates flow rates of the Parker and Ipswich Rivers, as reported by USGS, for two weeks preceding each of the ten receiving water surveys. Axes for the two rivers are scaled to their relative drainage basin area. The two rivers show essentially the same pattern of flow per area, but it appears that the much larger Ipswich is slower to respond to changes and thus lags behind the Parker. The dramatic difference between 1992 and 1993 in freshwater flow to Plum Island Sound is quite evident in this figure.

3.342. Box Model Calculations

The box model was setup and applied for four of the receiving water surveys in 1992 and each of the five 1993 surveys as well as for the mean of the surveys within each year. The model requires a variety of input parameter values including volume of each box, freshwater flow and mean salinity. The results of the area and volume calculations for the model box subregions are shown in Table 3.31. Some of these areas are defined differently between years as the Minibay Project fine-tuned its sampling program.

Jerome et al. (1968) also calculated areas and volumes for the Plum Island Sound

System (see Chapter 2). They reported a low tide area about 36% greater than calculated by Applied Science Associates, Inc. for the Minibay Project and a nearly identical low tide volume. They found a high tide area only 3% greater than reported here with a high tide volume about 34% greater. These differences may represent changes in the Sound or differences in interpretation of data from the charts. The considerably larger range of mean depth found by Jerome et al. than found by the Minibay Project is very likely due to a difference in interpretation of bathymetry of intertidal areas at high tide.

Mean salinity values for each box were calculated from the mean for each station for each survey day. The results of these calculations are given in Table 3.32 for 1992 and Table 3.33 for 1993. The model assumes that freshwater runoff from land is diluting ocean seawater from Ipswich Bay. Consistent with this assumption is a gradient of decreasing salinity from the mouth of the Sound up the Sound and up the rivers. When this assumption is not met by the data, the model will not work properly. During the third survey in 1993 the salinity in the Sound and the Rowley River slightly exceeded the value at Station 1, representing the open boundary. The station 1 value was increased slightly (0.02 ppt) to correct this condition so that the model assumptions would be met. Both this problem and the correction are consistent with a high flushing rate of the Sound where values of a small tributary closely approximate that of oceanic conditions. While the flushing values thereby calculated may not be "correct", they should reflect the right order of magnitude.

Freshwater flow to Plum Island Sound by box, based on river flow per area from the Ipswich and Parker Rivers is given in Table 3.34 for the 1992 surveys and Table 3.35 for the 1993 surveys.

Data from Tables 3.31-3.36 were incorporated into setup files for the box model which was then run for each case. Flushing times for individual survey days represent a range of values (Table 3.36). Using the mean values, the box model calculates a flushing time for the Sound of 1.9 days and for the rivers (except for Plum Island River) a range of 0.3 to 4.5 days for 1992. Given the volume and tidal prism of the Sound system, these values seem to be of an appropriate scale.

The very long 43 day flushing time for Plum Island River suggests an error of the method or its assumptions. Since this high value carries through all sampling surveys run, it is unlikely to be a salinity measurement error. More probably, the error is in evaluating freshwater inflow. It was assumed that water from the Merrimack River does not routinely reach Plum Island Sound by way of the Plum Island River. However, this is the only probable source for what must be a significant amount of freshwater diluting the waters of the Plum Island River. We have no value for what this inflow from the Merrimack might be, but if the freshwater inflow to Plum Island River for the average 1992 case is increased from 0.11 m^3/sec (this is inflow based on assumed watershed, including marsh areas) to 2.2, a factor of 20, then flushing time is recalculated to be about 2.2 days, comparable to that of the Sound. This is a freshwater input value comparable to the concurrent input from the Parker River and about a quarter that coming in from the

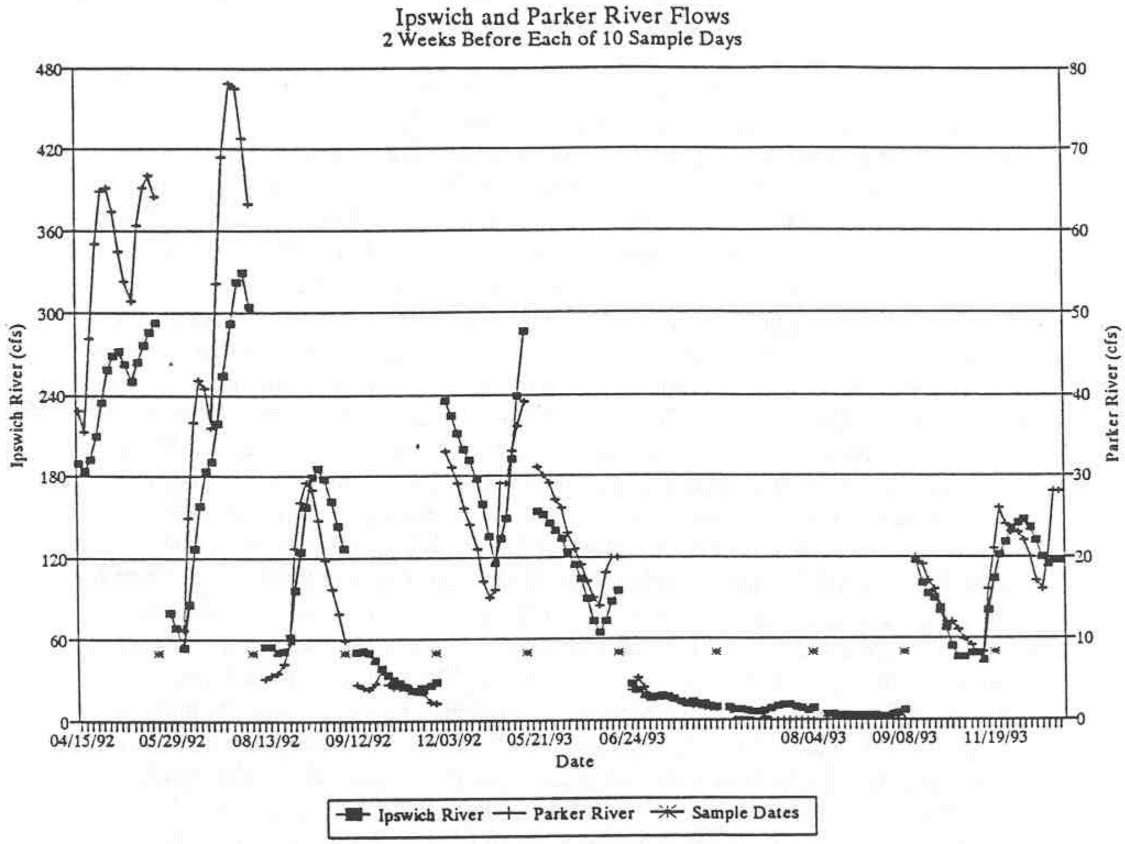


Figure 3.3. Streamflow in cubic feet per second reported by the Ipswich and Parker USGS gauges for two weeks preceding each of the ten receiving water surveys of Plum Island Sound carried out by ASA, Inc. The axes for the two curves (Ipswich = left axis, Parker = right axis) have been scaled to relative drainage area.

Ipswich River. Note also that since most of this freshwater will eventually pass to the Sound, an increased freshwater input to the Plum Island River also results in the calculation of a reduced flushing time for the Sound. In the case of the 20-fold increase discussed above, the corresponding flushing time for the Sound is reduced from 1.9 to 1.6 days.

Several aspects of the survey program changed in 1993. There were more salinity sampling stations, the arrangement of boxes was altered, and it was a very dry summer. The results of the flushing calculations were quite different as well. As in 1992, a wide range of values resulted from calculations from the five single surveys (Table 3.36). Flushing time for box 1, the main area of the Sound, for the average condition in 1993 was calculated to be only 0.76 days, half of that calculated for the Sound in 1992. At the same time, the model calculates flushing times in the rivers in 1993 that are about twice those calculated for 1992. These differences are due in some part to the increased coverage of salinity sampling that took place in 1993. Recalculating the 1993 average case using only the stations measured in 1992 (where data is available) gives flushing times of 1.05 days for the Sound, 0.76 days for the lower Ipswich, 6.0 days for the Rowley, 3.1 days for the lower Parker and 14.2 days for the upper Parker.

Table 3.31. Calculated areas and volumes for the model boxes for the 1992 and 1993 surveys.

Box	Name	Low tide area - m^2	Low tide volume - m^3	High tide area - m^2	High tide volume - m^3	Mean area - m^2	Mean volume - m^3

1992 Surveys

1	Plum Island Sound	5,976,170	13,767,800	12,334,600	30,125,300	9,155,385	21,946,550
2	Ipswich River	193,690	157,244	1,666,298	2,493,023	929,994	1,325,134
3	Rowley River	448,059	511,345	950,424	1,848,710	699,242	1,180,028
4	Plum Island River	213,072	275,708	1,209,150	1,997,660	711,111	1,136,684
5	Lower Parker River	739,309	1,042,600	974,507	2,519,330	856,908	1,780,965
6	Upper Parker River	437,457	1,142,400	473,457	1,732,260	455,457	1,437,330

1993 Surveys

1	South Plum Island Sound	5,339,796	12,805,219	10,733,447	26,462,420	8,036,622	19,633,820
2	Lower Ipswich River	173,013	143,004	1,581,600	2,352,530	877,307	1,247,767
3	Upper Ipswich River	20,677	14,240	84,698	140,493	52,688	77,367
4	Rowley River	448,059	511,345	950,424	1,848,710	699,242	1,180,028
5	North Plum Island Sound	849,446	1,238,289	2,810,303	5,660,540	1,829,875	3,449,415
6	Lower Parker River	739,309	1,042,600	974,507	2,519,330	856,908	1,780,965
7	Upper Parker River	437,457	1,142,400	473,457	1,732,260	455,457	1,437,330

Whole System

Sum	Plum Island Sound/Rivers	8,007,757	16,897,097	17,608,436	40,716,283	12,808,097	28,806,690

Table 3.32. Average salinity by box for the 1992 surveys, with averages by box for surveys 1, 2, 4 and 5.

Survey	Date	Station	Box	Salinity	Comments
1992-1	04/28/92	1	Open Boundary	26.86	
1992-1	04/28/92	12,22	1	22.70	
1992-1	04/28/92	2	2	21.07	
1992-1	04/28/92	9	3	20.34	
1992-1	04/28/92	23	4	10.25	
1992-1	04/28/92	15	5	9.61	
1992-1	04/28/92	21	6	1.55	
1992-2	06/11/92	1	Open Boundary	28.03	
1992-2	06/11/92	12,22	1	25.43	
1992-2	06/11/92	2	2	23.05	
1992-2	06/11/92	9	3	23.77	
1992-2	06/11/92	23	4	14.85	
1992-2	06/11/92	15	5	16.42	
1992-2	06/11/92	21	6	10.59	
1992-4	09/25/92	1	Open Boundary	30.62	
1992-4	09/25/92	12,22	1	30.09	
1992-4	09/25/92	2	2	28.93	
1992-4	09/25/92	9	3	29.92	
1992-4	09/25/92	23	4	28.19	
1992-4	09/25/92	15	5	27.84	
1992-4	09/25/92	21	6	17.44	
1992-5	12/16/92	1	Open Boundary	29.98	
1992-5	12/16/92	12,22	1	26.50	
1992-5	12/16/92	2	2	22.27	
1992-5	12/16/92	9	3	25.61	
1992-5	12/16/92	23	4	19.90	
1992-5	12/16/92	15	5	20.95	
1992-5	12/16/92	21	6	6.53	
1992-avg	Surveys 1,2,4,5	1	Open Boundary	28.87	
1992-avg	Surveys 1,2,4,5	12,22	1	26.18	
1992-avg	Surveys 1,2,4,5	2	2	23.83	
1992-avg	Surveys 1,2,4,5	9	3	24.91	
1992-avg	Surveys 1,2,4,5	23	4	18.30	
1992-avg	Surveys 1,2,4,5	15	5	18.71	
1992-avg	Surveys 1,2,4,5	21	6	9.03	

Table 3.33. Average salinity by box for the 1993 surveys, with averages for surveys 2 - 5.

Survey	Date	Box	Stations	Salinity	Comments
1993-1	06/03/93	Open boundary	1	30.00	
1993-1	06/03/93	1	6,7,12	28.00	
1993-1	06/03/93	2	2,3,4	25.02	
1993-1	06/03/93	3	5	16.13	Set value
1993-1	06/03/93	4	8,9,10,11	25.10	
1993-1	06/03/93	5	13,14	ND	
1993-1	06/03/93	6	15,16,17	ND	
1993-1	06/03/93	7	18,19,20,21	ND	
1993-2	07/09/93	Open boundary	1	30.78	
1993-2	07/09/93	1	6,7,12	30.66	
1993-2	07/09/93	2	2,3,4	29.45	
1993-2	07/09/93	3	5	27.27	
1993-2	07/09/93	4	8,9,10,11	30.37	
1993-2	07/09/93	5	13,14	29.61	
1993-2	07/09/93	6	15,16,17	28.39	
1993-2	07/09/93	7	18,19,20,21	23.48	
1993-3	08/04/93	Open boundary	1	30.83	Set value
1993-3	08/04/93	1	6,7,12	30.82	
1993-3	08/04/93	2	2,3,4	29.18	
1993-3	08/04/93	3	5	27.52	
1993-3	08/04/93	4	8,9,10,11	30.81	
1993-3	08/04/93	5	13,14	30.32	
1993-3	08/04/93	6	15,16,17	29.77	
1993-3	08/04/93	7	18,19,20,21	26.98	
1993-4	09/08/93	Open boundary	1	30.74	
1993-4	09/08/93	1	6,7,12	30.70	
1993-4	09/08/93	2	2,3,4	29.82	
1993-4	09/08/93	3	5	28.11	
1993-4	09/08/93	4	8,9,10,11	29.89	
1993-4	09/08/93	5	13,14	30.48	
1993-4	09/08/93	6	15,16,17	30.18	
1993-4	09/08/93	7	18,19,20,21	28.55	
1993-5	12/02/93	Open boundary	1	29.83	
1993-5	12/02/93	1	6,7,12	29.27	
1993-5	12/02/93	2	2,3,4	21.95	
1993-5	12/02/93	3	5	15.48	
1993-5	12/02/93	4	8,9,10,11	24.55	
1993-5	12/02/93	5	13,14	26.79	
1993-5	12/02/93	6	15,16,17	23.59	
1993-5	12/02/93	7	18,19,20,21	16.31	
1993-avg	Surveys 2 to 5	Open boundary	1	30.54	
1993-avg	Surveys 2 to 5	1	6,7,12	30.36	
1993-avg	Surveys 2 to 5	2	2,3,4	27.60	
1993-avg	Surveys 2 to 5	3	5	24.59	
1993-avg	Surveys 2 to 5	4	8,9,10,11	28.91	
1993-avg	Surveys 2 to 5	5	13,14	29.30	
1993-avg	Surveys 2 to 5	6	15,16,17	27.98	

1993-avg	Surveys 2 to 5	7	18,19,20,21	23.83	

Table 3.34. Calculations for freshwater flow to model box subareas during the 1992 surveys. Areas are based on subbasin areas from Mass. GIS plus areas given by USGS for the Parker and Ipswich River gauges. Flow rates are based on flows reported by USGS for the Ipswich and Parker Rivers, weighted by area and extrapolated to the entire subbasin area.

Survey	Date	Box	Stations	Drainage Area	Stream Flow/Area	Stream Flow Rate
				km^2	$m^3/sec/km^2$	m^3/sec
1992-1	04/28/92	1	12,22	20.93	0.0267	0.559
1992-1	04/28/92	2	2	402.51	0.0267	10.747
1992-1	04/28/92	3	9	25.36	0.0267	0.677
1992-1	04/28/92	4	23	5.51	0.0267	0.147
1992-1	04/28/92	5	15	27.17	0.0267	0.725
1992-1	04/28/92	6	21	126.96	0.0267	3.390
1992-2	06/11/92	1	12,22	20.93	0.0274	0.573
1992-2	06/11/92	2	2	402.51	0.0274	11.029
1992-2	06/11/92	3	9	25.36	0.0274	0.695
1992-2	06/11/92	4	23	5.51	0.0274	0.151
1992-2	06/11/92	5	15	27.17	0.0274	0.744
1992-2	06/11/92	6	21	126.96	0.0274	3.479
1992-4	09/25/92	1	12,22	20.93	0.00223	0.047
1992-4	09/25/92	2	2	402.51	0.00223	0.898
1992-4	09/25/92	3	9	25.36	0.00223	0.057
1992-4	09/25/92	4	23	5.51	0.00223	0.012
1992-4	09/25/92	5	15	27.17	0.00223	0.061
1992-4	09/25/92	6	21	126.96	0.00223	0.283
1992-5	12/16/92	1	12,22	20.93	0.0243	0.509
1992-5	12/16/92	2	2	402.51	0.0243	9.781
1992-5	12/16/92	3	9	25.36	0.0243	0.616
1992-5	12/16/92	4	23	5.51	0.0243	0.134
1992-5	12/16/92	5	15	27.17	0.0243	0.660
1992-5	12/16/92	6	21	126.96	0.0243	3.085
1992-avg	4-day	1	12,22	20.93	0.0202	0.423
1992-avg	4-day	2	2	402.51	0.0202	8.131
1992-avg	4-day	3	9	25.36	0.0202	0.512
1992-avg	4-day	4	23	5.51	0.0202	0.111
1992-avg	4-day	5	15	27.17	0.0202	0.549
1992-avg	4-day	6	21	126.96	0.0202	2.565

Table 3.35. Calculations for freshwater flow to model box subareas during the 1993 surveys. Areas are based on subbasin areas from Mass. GIS plus areas given by USGS for the Parker and Ipswich River gauges. Flow rates are based on flows reported by USGS for the Ipswich and Parker Rivers, weighted by area and extrapolated to the entire subbasin area.

Survey	Date	Box	Stations	Drainage Area	Stream Flow/Area	Stream Flow Rate
				km^2	$m^3/sec/km^2$	m^3/sec
1993-1	06/03/93	1	6,7,12	17.16	0.00859	0.147
1993-1	06/03/93	2	2,3,4	12.83	0.00859	0.110
1993-1	06/03/93	3	5	389.68	0.00859	3.347
1993-1	06/03/93	4	8,9,10,11	25.36	0.00859	0.218
1993-1	06/03/93	5	13,14	9.28	0.00859	0.080
1993-1	06/03/93	6	15,16,17	27.17	0.00859	0.233
1993-1	06/03/93	7	18,19,20,21	126.96	0.00859	1.091
1993-2	07/09/93	1	6,7,12	17.16	0.00085	0.015
1993-2	07/09/93	2	2,3,4	12.83	0.00085	0.011
1993-2	07/09/93	3	5	389.68	0.00085	0.331
1993-2	07/09/93	4	8,9,10,11	25.36	0.00085	0.022
1993-2	07/09/93	5	13,14	9.28	0.00085	0.008
1993-2	07/09/93	6	15,16,17	27.17	0.00085	0.023
1993-2	07/09/93	7	18,19,20,21	126.96	0.00085	0.108
1993-3	08/04/93	1	6,7,12	17.16	0.00074	0.013
1993-3	08/04/93	2	2,3,4	12.83	0.00074	0.009
1993-3	08/04/93	3	5	389.68	0.00074	0.288
1993-3	08/04/93	4	8,9,10,11	25.36	0.00074	0.019
1993-3	08/04/93	5	13,14	9.28	0.00074	0.007
1993-3	08/04/93	6	15,16,17	27.17	0.00074	0.020
1993-3	08/04/93	7	18,19,20,21	126.96	0.00074	0.094
1993-4	09/08/93	1	6,7,12	17.16	0.00058	0.010
1993-4	09/08/93	2	2,3,4	12.83	0.00058	0.007
1993-4	09/08/93	3	5	389.68	0.00058	0.226
1993-4	09/08/93	4	8,9,10,11	25.36	0.00058	0.015
1993-4	09/08/93	5	13,14	9.28	0.00058	0.005
1993-4	09/08/93	6	15,16,17	27.17	0.00058	0.016
1993-4	09/08/93	7	18,19,20,21	126.96	0.00058	0.074
1993-5	12/02/93	1	6,7,12	17.16	0.00934	0.160
1993-5	12/02/93	2	2,3,4	12.83	0.00934	0.120
1993-5	12/02/93	3	5	389.68	0.00934	3.640
1993-5	12/02/93	4	8,9,10,11	25.36	0.00934	0.237
1993-5	12/02/93	5	13,14	9.28	0.00934	0.087
1993-5	12/02/93	6	15,16,17	27.17	0.00934	0.254
1993-5	12/02/93	7	18,19,20,21	126.96	0.00934	1.186
1993-avg	4-day	1	6,7,12	17.16	0.0029	0.050
1993-avg	4-day	2	2,3,4	12.83	0.0029	0.037
1993-avg	4-day	3	5	389.68	0.0029	1.130
1993-avg	4-day	4	8,9,10,11	25.36	0.0029	0.074
1993-avg	4-day	5	13,14	9.28	0.0029	0.027
1993-avg	4-day	6	15,16,17	27.17	0.0029	0.079
1993-avg	4-day	7	18,19,20,21	126.96	0.0029	0.368

Table 3.36. Model calculated flushing times in days for the two survey years with flushing times for the average conditions calculated for four of the surveys in each year.

1992 Surveys

Box	Name	Stations	Survey 1	Survey 2	Survey 4	Survey 5	Average
1	Plum Island Sound	12,22	2.42	1.41	3.24	1.99	1.93
2	Ipswich River	2	0.31	0.25	0.94	0.40	0.33
3	Rowley River	9	4.90	2.99	5.48	3.23	3.66
4	Plum Island River	23	55.34	40.97	87.01	33.01	43.39
5	Lower Parker River	15	3.22	2.02	5.44	1.66	2.33
6	Upper Parker River	21	4.62	2.98	25.30	4.22	4.46

1993 Surveys

Box	Name	Stations	Survey 1	Survey 2	Survey 3	Survey 4	Survey 5	Average (2, 3, 4, 5)
1	South Plum Island Sound	6,7,12	2.90	1.71	0.16	0.84	0.75	0.76
2	Lower Ipswich River	2,3,4	0.69	1.82	2.60	1.86	1.01	1.19
3	Upper Ipswich River	5	0.12	0.31	0.33	0.34	0.12	0.15
4	Rowley River	8,9,10,11	10.23	8.27	0.47	25.18	10.20	9.85
5	North Plum Island Sound	13,14		10.92	5.46	3.55	2.66	3.42
6	Lower Parker River	15,16,17		12.22	6.22	4.17	2.99	3.87
7	Upper Parker River	18,19,20,21		36.53	22.10	16.02	6.36	9.93

The greater density of stations in 1993 gives preference to the calculations for 1993. Thus, any corrections to these calculations should be made to favor the 1993 values. Given this assumption, there remains a range of a factor of two for flushing time estimates for most of the boxes. If 1992 values are corrected to reflect the sample area differences noted above, the following ranges result: Box 1, the southern sound, has a flushing time in the range of three quarters to one and a half days. The lower Ipswich, Box 2, flushes in half a day to just over a day. The upper Ipswich flushes in a few hours. Box 4, the Rowley River, flushes in about six to ten days. We have only a poor sense of the flushing time of the northern part of the Sound and Plum Island River due to the problem of unknown input from the Merrimack River. The lower Parker River flushes in three to four days while the upper Parker River flushes in three to ten days.

Comparing relative streamflow rates from Tables 3.34 and 3.35 with calculated flushing times in Table 3.36, on a survey-by-survey basis, indicates that shorter flushing times are generally associated with higher stream flows. Because there are several marked variations from this patterns, it is difficult to provide a rigorous predictive relationship of flushing time to streamflow. However, it can be expected that generally the shorter range of flushing times noted above will occur during times of high streamflow and longerflushing times from these ranges will occur during low streamflow periods.

It appears, then, that freshwater in the Ipswich River leaves the Sound system quickly as it is carried out to Ipswich Bay on each tide, while the waters draining to the Rowley and Parker Rivers get carried only partly out of the Sound on each ebb tide with most of it returning on the flood. The sound itself flushes quite rapidly so that once freshwater enters the Sound it is rapidly removed to the ocean.

3.343. Comparison of Minibay Flushing Study with Other Results

Plum Island LTER: The flushing times calculated by ASA, Inc. were similar to those published by Vallino and Hopkinson (1998) as part of the Plum Island Ecosystem Long Term Ecological Research (PIE-LTER) study. Vallino and Hopkinson estimated flushing times based on a one dimension tidally-averaged, advection dispersion model with inputs from salinity distribution and the release of rhodamine dye from three locations over one tidal cycle. They built on a previous 1D advection dispersion model by Vorosmarty and Loder (1994) that had incorporated marsh surface flooding. Based on their model, Vallino and Hopkinson estimated flushing times ranging from 0.5 days in the lower estuary to 34 days at the extreme upper part of the tidal section of the Parker River (the latter further "up estuary" than ASA's measurements). Once again the flushing times were strongly influenced by river flow. At the time of this writing, Vallino and coworkers were developing a two dimensional hydrodynamic model that was intended to drive a 2D advection-dispersion model for the Sound.

FDA and DMF: A dye study conducted by the FDA and Massachusetts DMF (Gaines et al., 1992) in May of 1992 provided some insights into processes that are occurring in Plum Island Sound. This study evaluated dye dispersion and time of travel from three points in the Plum Island Sound System: Plum Island River, Littler River and Greenwood Creek (on the Ipswich River). The primary goal of these studies was to evaluate the potential impact of bacterial pollution at these sources on shellfish beds in Plum Island Sound. The studies also give useful information on the transport of water in the Sound system.

The Plum Island River study demonstrated convincingly that, at least under some conditions, water apparently coming from the Merrimack River moves south into the Plum Island River on the rising tide and exits into Plum Island Sound on the following falling tide. There was not sufficient information to quantify this flow, but it at least verified a transport of water not considered in the present study, but proposed to exist based on flushing rates. This is discussed further in relation to fecal coliform contamination in section 3.42

The Little River study traced dye from the Route 1A bridge on the Parker River, near the mouth of the Little River, almost to the mouth of the Sound on an ebbing tide. The study demonstrated that this transport is quite rapid, with dye detectable at Little Neck in three and a half hours, covering almost the full length of the Sound. Thus, any flushing that occurs in the lower Parker River is inseparable from flushing that occurs within Plum Island Sound as a whole.

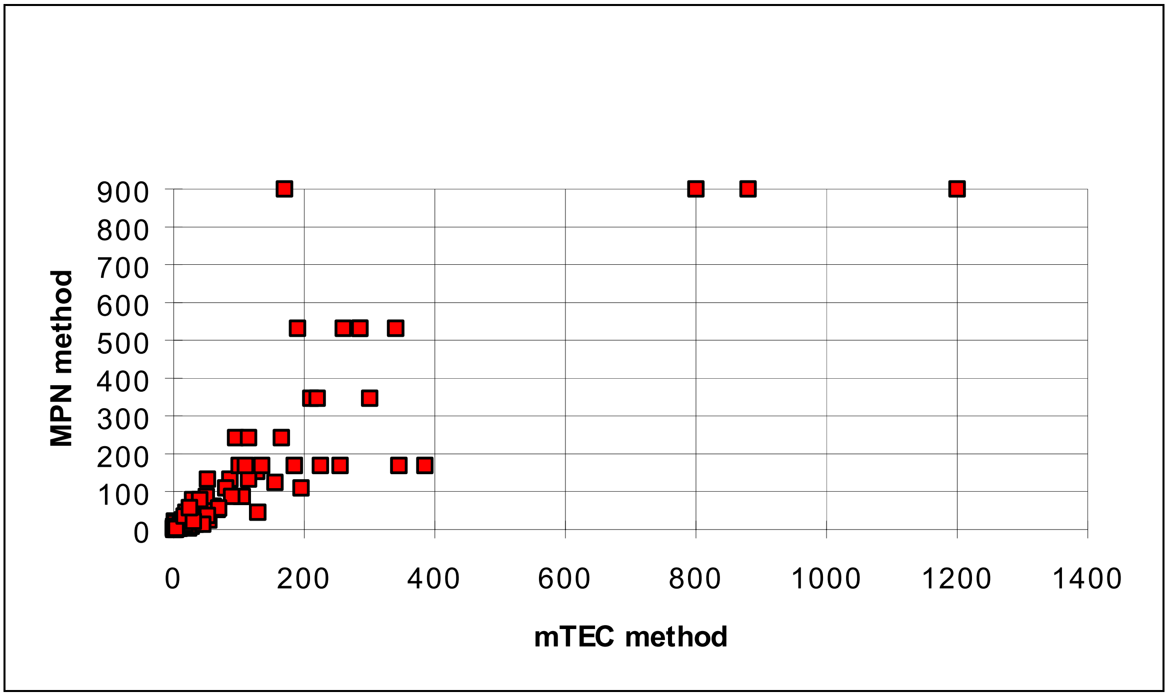
The Greenwood Creek study demonstrated that water in the Lower Ipswich River moves rapidly out of the river and is rapidly mixed vertically and horizontally in the process. At the turning of the tide, Ipswich River water overlay the Sound water and was carried into the Sound, slow mixing laterally and vertically. It became nearly indetectable before reaching Middle Ground. This reinforces what was learned in the present study, that the Ipswich River flushes rapidly and probably has a relatively small impact on flushing of the Sound as a whole.

3.35. Fecal coliform contamination of Plum Island Sound

3.351. Methodological Studies

There was a strong correlation between the fecal coliform concentrations measured by the mTEC membrane filtration method and DMF's results using the MPN procedures (Fig. 3.4). In general, the MPN data gave slightly higher readings for the same water sample, which is not surprising since the MPN method has been selected for use in sanitary surveys because it is conservative. There was also little difference between replicate samples, i.e. samples taken from either two different depths or the same depth at the same site (see Minibay Project report).

Fig. 3.4. Comparison of mTEC vs MPN methods for fecal coliforms in Plum Island Sound. Numbers are fecal coliforms per 100 ml of water.



3.352. Fecal coliform concentrations:

Plum Island Sound proper - The water of Plum Island Sound was characterized by low concentrations of fecal coliform bacteria during dry weather (Table 3.37). None of the geometric means calculated for dry weather indicated that levels were above 14 cfu per 100 ml, the state standard for harvesting shellfish. Only two sampling days were during wet weather, but this limited data indicated that fecal coliform levels are elevated above the state standard during rainfall events (Table 3.37). Not surprisingly, the Minibay Project sampling supported DMF's classification of most of the Sound as conditionally approved for shellfish harvesting.

Other than the Great Neck area in Ipswich, there were no obvious, significant direct sources of fecal coliform bacteria within the Sound proper. Instead, fecal coliforms entered Plum Island Sound through the Parker, Rowley and Ipswich Rivers, particularly during storm events.

Table 3.37. Geometric mean fecal coliform concentrations (as *E. coli*) in colony forming units per 100 ml. Plum Island Sound Stations.						
Station Location	**Station #**	**Station Type**	**# of Samples Dry**	**/ Wet**	**E. coli per 100 ml Dry Weather**	**Wet Weather**
Off Castle Hill	1	boat	7	2	3	38
Off Hellcat Swamp	12	boat	7	2	5	13
Eagle Hill River	22	boat	7	2	9	24
Rowley River Mouth	7	boat	3	1	2	8
Plum Island River at Jericho Creek	23	boat	6	2	10	12
Pine Island Creek	86	shore	4	3	15	51

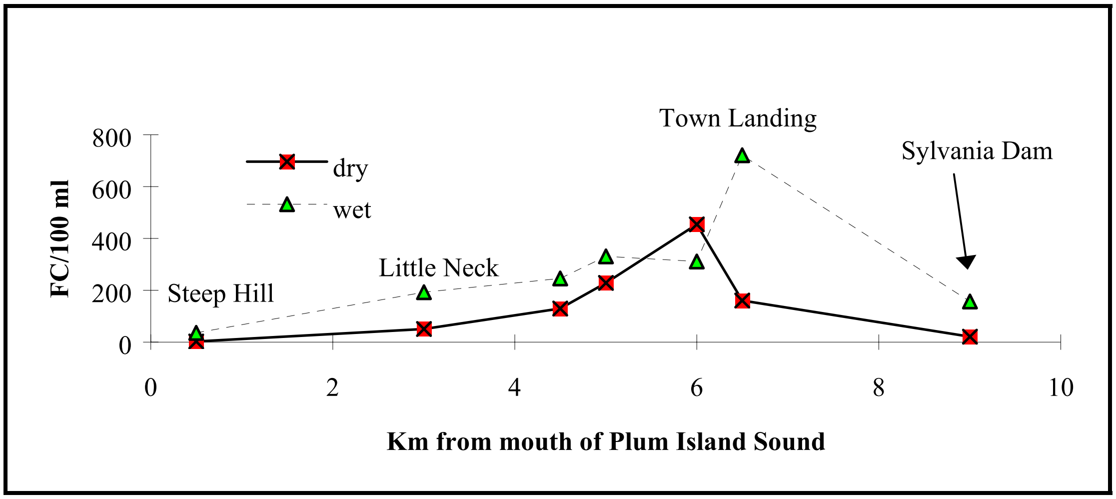
Ipswich River **-** High levels of fecal coliforms existed through much of the Ipswich River estuary and in three tributaries: Kimball Brook, Farley Brook, and Miles River during the study period (Table 3.38). Despite inputs from these tributaries, two of which are upstream of any stations on the main stem of the river, the main stem of the Ipswich River was relatively clean during dry weather before it enters downtown Ipswich (Fig. 3.5). This was based on relatively low concentrations of bacteria at the Sylvania Dam. Bacteria from upstream sources may settle out and die off behind the Sylvania Dam and in the extensive wetlands further upstream. As the water flowed between the Sylvania Dam and the town landing through downtown Ipswich, it received major inputs of bacteria. Farley Brook, which entered the Ipswich River after an underground passage of several hundred yards, was one of the major sources (but see below). Beyond the town landing station, bacterial concentrations gradually declined, probably through dilution and perhaps attenuation.

An extensive fecal coliform sampling program conducted by the Ipswich Coastal Pollution Control Committee (ICPCC) in Ipswich produced results similar to the Minibay Project. ICPCC's report indicated that Ipswich's faulty wastewater treatment plant and conveyance system contributed bacteria to the river as it makes its way through downtown Ipswich and that waterfowl, stormwater runoff and dogs were the other major contributors of fecal coliform to the main stem of the Ipswich River. According to ICPCC, horses and other agricultural inputs were believed to be significant sources of contamination to the Miles River (ICPCC, 1995).

The highest fecal coliform concentrations measured by the Minibay Project in the Ipswich River Basin were at the Kimball Brook station where average fecal coliform concentrations ranged from 804cfu/100 ml during dry weather to 3,605cfu/100 ml during wet weather. Based upon discussions with the Ipswich Board of Selectmen in November 1994, suspected illegal wastewater tie-ins to the stormwater drainage system were the major sources of contamination to the Kimball Brook.

Table 3.38. Geometric mean fecal coliform concentrations (as *E. coli*) in colony forming units per 100 ml. Ipswich River and its tributaries.						
Station Location	**Station #**	**Station Type**	**# of Samples Dry / Wet**		**E. coli per 100 ml Dry Weather**	**Wet Weather**
Miles River	74	shore	7	4	285	716
Kimball Brook	73	shore	8	5	804	3,605
Ipswich River at Sylvania Dam	71	shore	9	5	21	132
Farley Brook	72	shore	4	2	822	569
Ipswich River at Town Landing	5	boat	6	2	308	516
Ipswich R. at Labor in Vain Creek	4	boat	3	1	230	336
Ipswich River at Treadwell Island	3	boat	3	1	131	246
Ipswich River at Little Neck	2	boat	7	2	51	193

Fig. 3.5 Gradient of fecal coliforms – Ipswich River segment

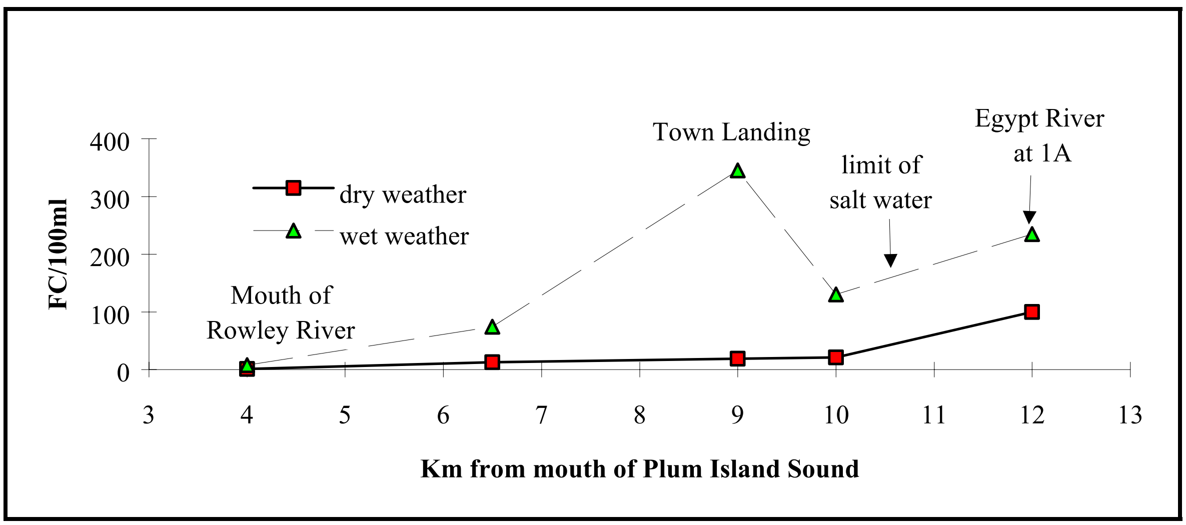


Rowley River - Fecal coliform concentrations in the Rowley River were relatively low during dry weather and moderately high after heavy rainstorms (Table 3.39). The main stem of the Rowley had average fecal coliform concentrations less than 25/100 ml during dry weather, slightly above the state standard for shellfishing. The moderate fecal coliform contamination throughout the Rowley River after heavy rainfalls suggests that there were inputs of contaminated stormwater. Average fecal coliform concentrations during wet weather ranged from 75/100 ml to 346. The higher bacteria concentrations during wet weather were apparently diluted before entering the Sound (Fig. 3.6).

Table 3.39. Geometric mean fecal coliform concentrations in the Rowley River and its tributaries. Results are expressed as cfu/100 ml.

Station Location	Station #	Station Type	# of Samples		E. coli per 100 ml	
			Dry	Wet	Dry Weather	Wet Weather
Egypt River at Route 1A	52	shore	14	4	105	236
Muddy Run at Paradise Road	53	shore	1	3	19	344
Rowley River at Town Landing	51	shore	5	2	22	131
Rowley River at Batchelder Lndg.	11	boat	3	1	20	346
Rowley River near Sound	9	boat	7	2	14	75

Fig. 3.6. Gradient of Fecal Coliforms - Rowley River Segment



Parker River - Although the main stem of the Parker River was relatively clean during dry weather, many of its tributaries, most notably Ox Pasture Brook, and the Mill and Little Rivers, regularly contained high concentrations of fecal coliforms even during dry weather (Table 3.40). The station with the highest level of contamination in the Parker River basin was a small tributary creek to the Mill River where average fecal coliform counts are 1998/100 ml during dry weather to 5624 after rainfall. These extremely high counts, which have exceeded 100,000 several times, were probably related to problems with the sewage treatment plant at the Governor Dummer Academy. The Academy has made repairs to the system under the guidance of DEP.

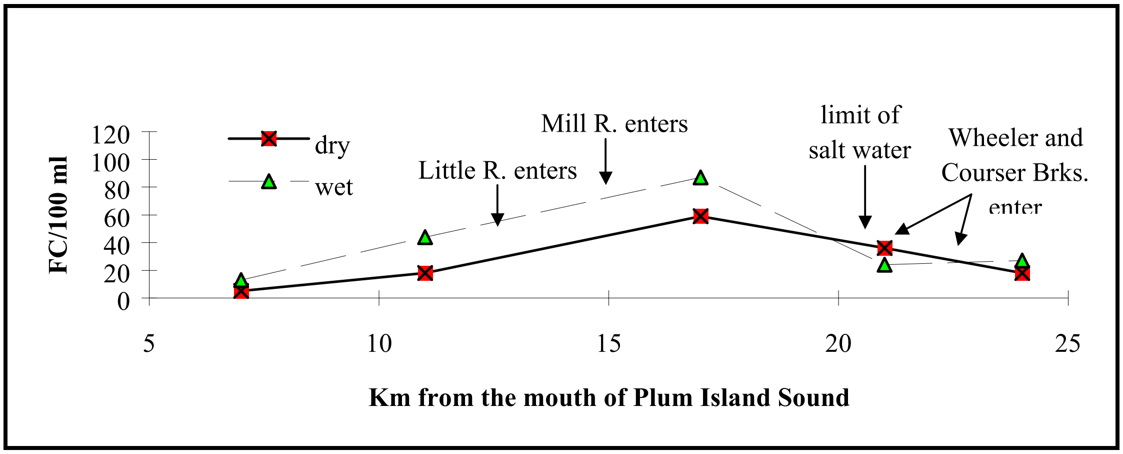
A shoreline survey conducted as part of the Minibay Project indicated that horses and agricultural inputs were major sources of contamination to the Mill River and Wheeler Brook. Possible sources of fecal coliforms in Ox Pasture Brook were horses, duck ponds and failing septic systems. Fecal coliforms in the Little River were most likely from failing septic systems. Fecal coliform concentrations actually declined during wet weather events in two of our sampling stations along the Little River, suggesting that contamination from faulty septic systems was diluted after rainfall. Domestic animals may have been another source of fecal contamination to the Little River.

Table 3.40. Geometric Mean Fecal Coliform Concentrations in cfu/100 ml. Parker River and its tributaries.

Station Location	Station #	Station Type	# of Samples Dry	Wet	E. coli per 100 ml Dry Weather	Wet Weather
Parker River at Main St. - Byfield	46	shore	5	5	18	27
Wheeler Brook at Larkin Rd.	48	shore	11	7	303	351
Courser Brook at Orchard Street	45	shore	10	8	130	243
Parker River at Central Street	44	shore	15	8	36	24
Parker River at Route 1	21	both	13	6	59	87
Parker River off Newbury Landing	15	both	12	6	18	44
Mill River at Wethersfield St.	32	shore	6	4	130	762
Bachelder Brook at Wethersfield St.	33	shore	5	4	32	162
Mill River at Glen Mills	31	shore	18	7	59	65
Creek near Governor Dummer	37	shore	11	5	1,998	5,624
Mill River near Parker River	24	boat	6	2	76	181
Ox Pasture Brook at Independ. St.	36	shore	4	2	788	3,246
Ox Pasture Brook at School St.	35	shore	4	1	615	1,081
Ox Pasture Brook at Fenno Drive	34	shore	16	7	414	982
Little River at Scotland Road	84	shore	4	3	38	548
Little River at Hanover Street	83	shore	12	2	380	556
Little River at Boston Street	82	shore	1	1	241	176
Little River at Newman Road	81	shore	5	2	165	157
Little River near Parker River	25	shore	6	2	38	98

The main stem of the Parker River (water coming over the dam in Byfield) was relatively clean (Fig. 3.7). However, within the estuarine part of this river, inputs from the Mill and Little Rivers caused a slight increase in bacteria which was then gradually diluted before the Parker River flowed into Plum Island Sound.

Fig. 3.7. Gradient of fecal coliforms - Parker River segment



Parker River National Wildlife Refuge - Fecal coliform samples from several sites in the Parker River National Wildlife Refuge (PRNWR) were collected to determine contamination levels in areas where wildlife was the only likely source (Table 3.6). Samples were taken in May 1993 and August - December 1994, and therefore covered times of spring and fall migrations when numbers of birds on the refuge were likely to be at the highest levels. Hellcat Swamp and Stage Island, two ponds with the heaviest concentrations of waterfowl on the refuge, had somewhat elevated levels of fecal coliforms (53 and 33 respectively). Other sampling stations had much less.

At the salt pannes wildlife viewing area, samples for bacteria that might be within the top layers of the sediment were taken by stirring up the sediment and then collecting the resulting sediment plume (Table 3.42). No fecal coliforms were detected in these samples, perhaps due to interference by the sediment with the membrane filtration procedure.

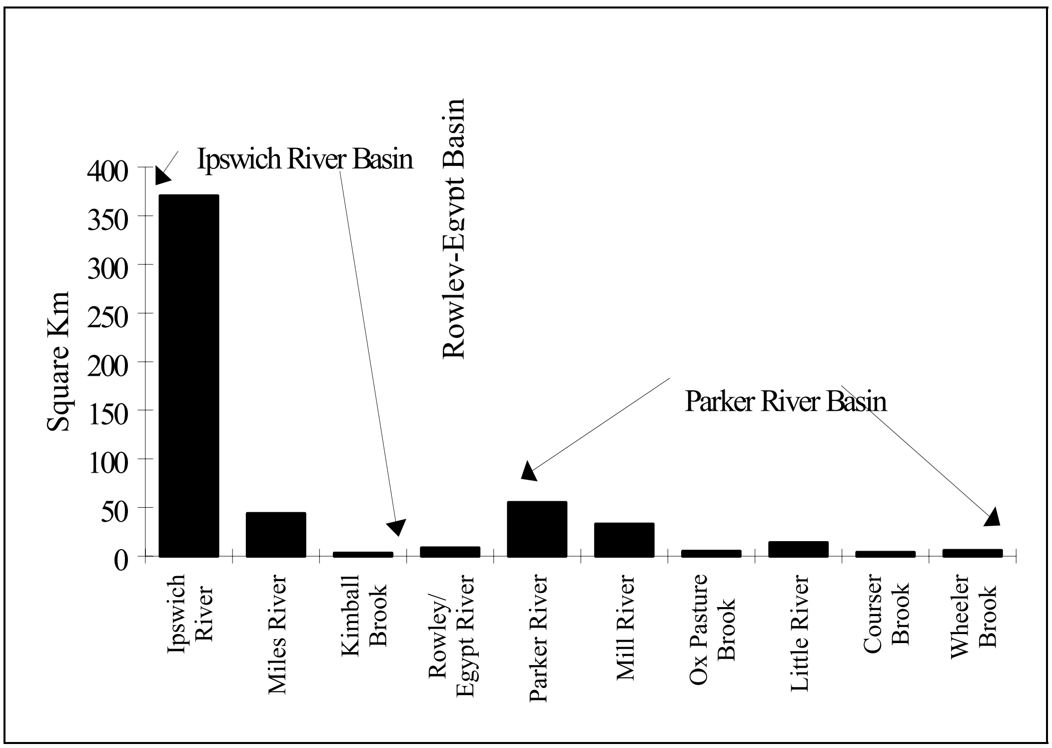
Only one wet weather event was sampled on the PRNWR. Fecal coliform concentrations were elevated at all stations with a one and two orders of magnitude increase over dry weather at the Hellcat Swamp and Salt Panne stations respectively.

Table 3.41. Geometric Mean Fecal Coliform Concentrations in cfu/100 ml. Parker River NWR.						
Station Location	**Station #**	**Station Type**	**# of Samples**		**E. coli per 100 ml**	
			Dry	**Wet**	**Dry Weather**	**Wet Weather**
Stage Island Outlet	61	shore	9	1	33	90
Pine Creek	62	shore	9	1	10	25
Hellcat Swamp Outlet	63	shore	9	1	53	661
Salt Pannes	64	shore	6	1	7	601
Sediment in Salt Pannes	64.5	shore	3	0	0	nd
Plum Island River	65	shore	6	0	8	nd

3.353. Loadings of fecal coliforms to Plum Island Sound from various sources

Fecal coliform bacteria are carried into Plum Island Sound by the Ipswich, Parker and Rowley rivers. The Ipswich basin is by far the largest, roughly 4 times larger than the Parker (Fig. 3.8). The Rowley River basin is relatively small compared to the other two basins.

Fig. 3.8. Drainage Basin Areas of Plum Island Sound.



The Ipswich River supplied roughly three fourths of the freshwater input to Plum Island Sound and was responsible for over 90 percent of the fecal coliform loadings to the Sound during both dry and wet weather (Fig. 3.9). Most of this loading (over 70% of the fecal coliforms during dry weather and 52% during wet weather) originated from the center of Ipswich between the Sylvania Dam and the town wharf. Because the Ipswich River enters the Sound at its mouth, this contamination was flushed rapidly out of the Sound into Ipswich Bay at low tides. Therefore, despite the large bacterial loads carried by the Ipswich River, the Ipswich did not likely have a major impact on water quality throughout most the Sound. The Ipswich River had negligible impact on the central and northern parts of the Sound where many clam flats are located.

The Parker River was the greatest source of fecal coliforms to the central and northern sections of the Sound (Figs. 3.9-3.10). Although the volume of freshwater input to Plum Island Sound from the Parker River was much lower than the volume contributed by the Ipswich River, the Parker River basin affected water quality throughout the Sound because it empties into the upper reaches of the Sound. The Little River in Newbury was the largest source of bacteria to the Parker River (about 40% in both dry and wet weather).

The Rowley River and the PRNWR did not contribute significantly to fecal coliform loadings in Plum Island Sound (Fig. 3.9-3.10). The volume of water contributed to the Sound from the Rowley River was relatively low, and the moderate concentrations of fecal coliform generally died off before they enter the Sound. Fecal coliform contamination from birds in the PRNWR did not contribute significantly to pollution loadings in the Sound because there is little or no flow from these areas into the Sound.

Fig. 3.9. Relative loadings of fecal coliforms to Plum Island Sound from all basins

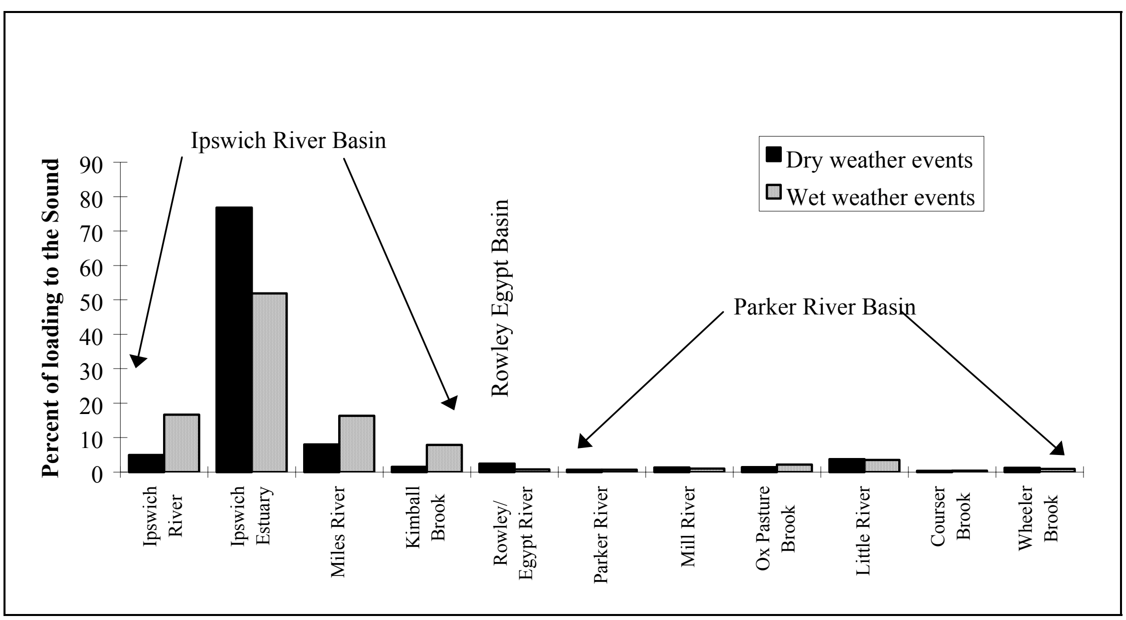
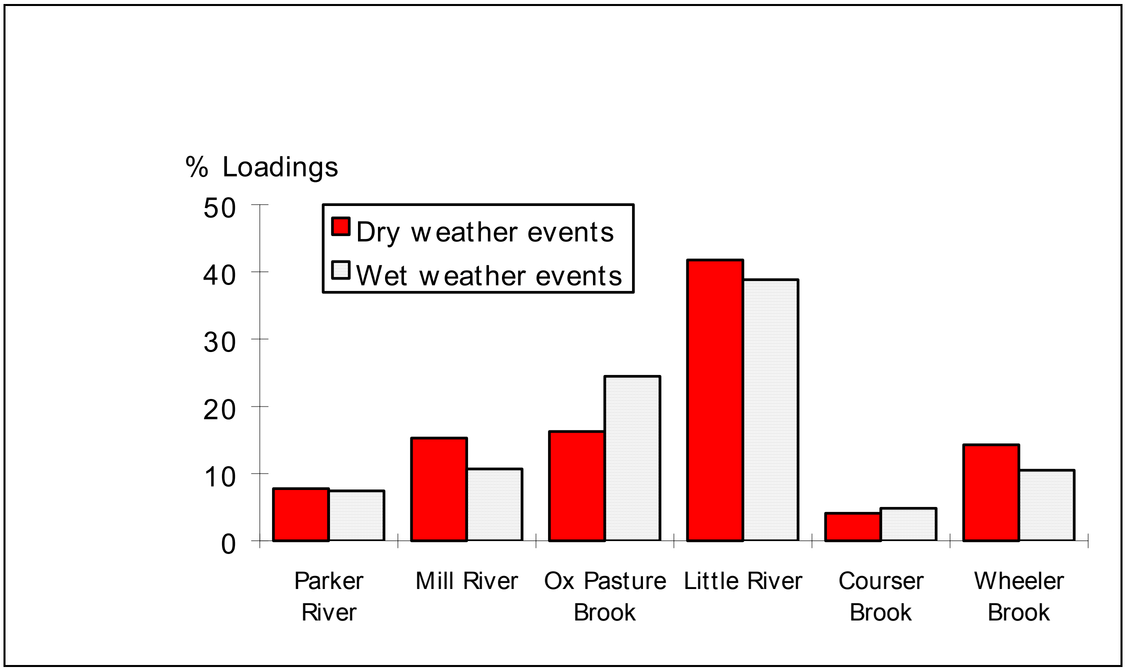


Fig. 3.10. Relative loadings of fecal coliforms to Plum Island Sound, Parker River basin only.

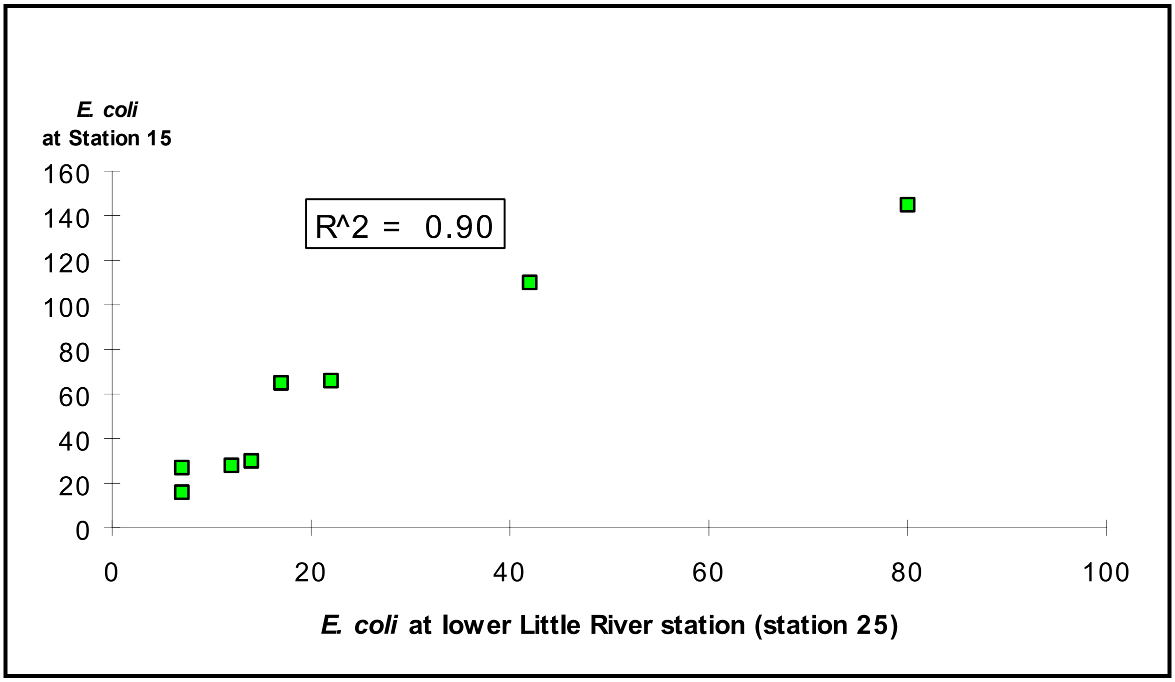


3.353. Correlations between sampling stations

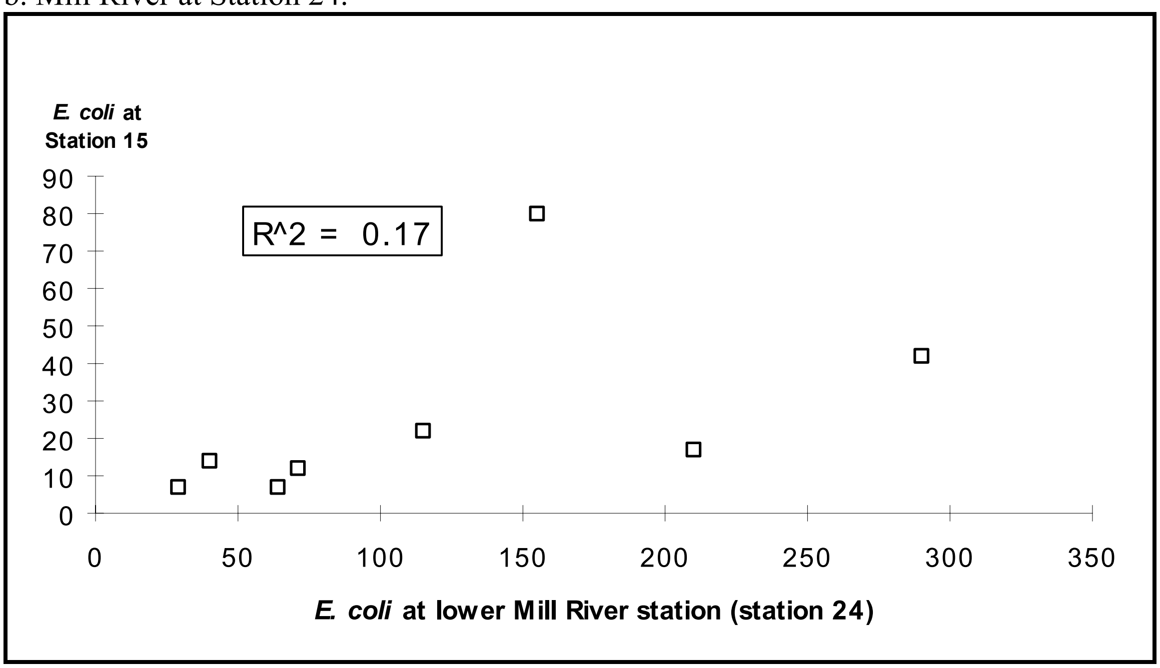
As a way of inferring which tributaries might be contributing to fecal coliform loads in the Sound, fecal coliform concentrations in upstream sampling stations were correlated with those downstream on the same sampling day. In the Parker River system, station MAS15, near the Parker's mouth, receives water from the main stem of the Parker as well as the Mill and Little Rivers. Sample station MAS25 on the Little, MAS24 on the Mill, and MAS21 on the Parker River are all within about 2 kilometers upstream of station 15. There is a strong correlation between the fecal coliform concentrations in the Little River and those at station 15 on the Parker (Fig. 3.11a). In contrast, there is no obvious relationship between station 15 and two upstream sampling stations on the Mill River and the main stem of the Parker (Fig. 3.11b-c). This suggests that the Little River has a major impact on clam flats that are in the region where the Parker River joins the Sound.

Fig. 3.11. Influence of three upstream stations on fecal coliforms in the lower Parker River at station 15. Low tide samples only.

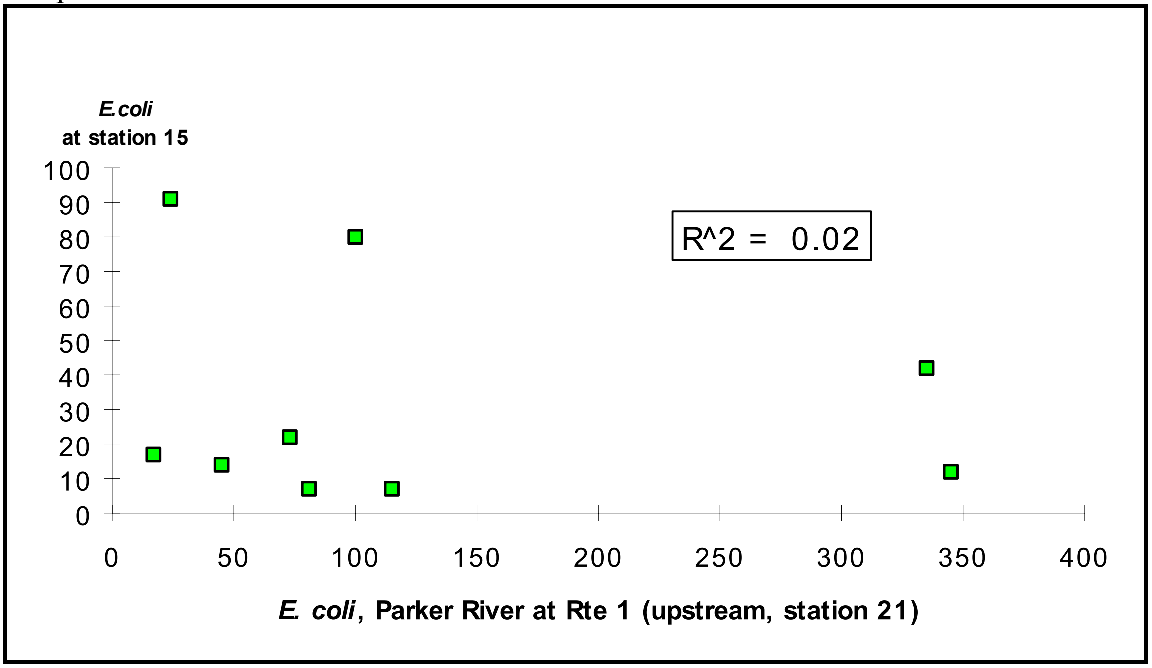
a. Little River at Station 25.



b. Mill River at Station 24.

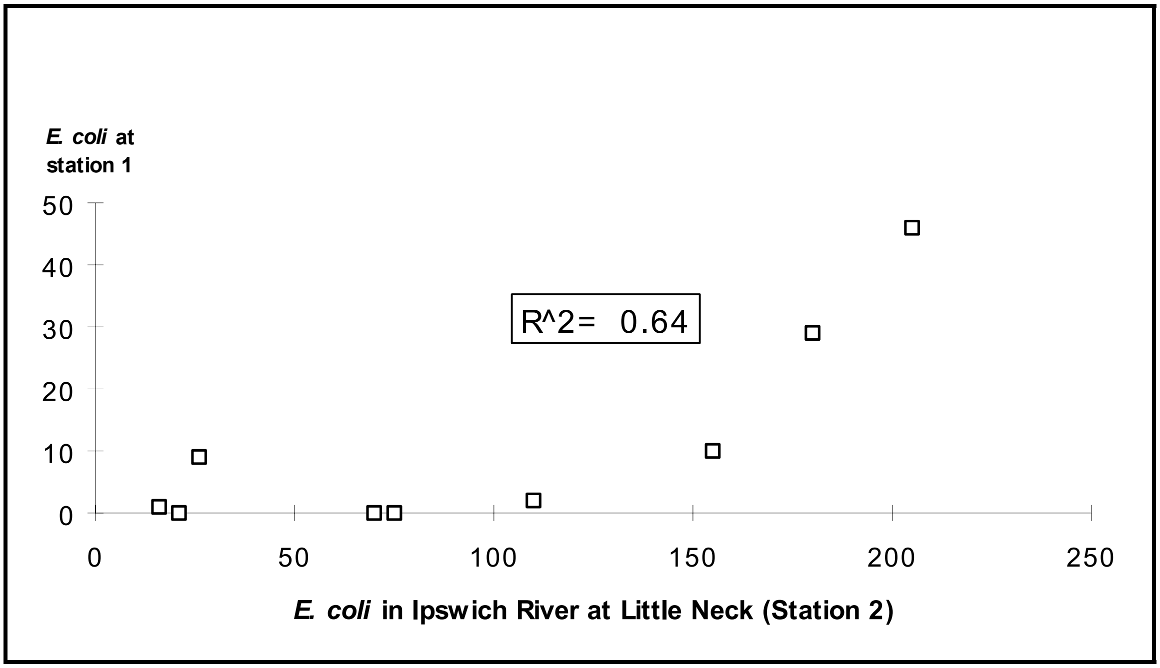


c. Upstream Parker River at Station 21.



Fecal coliform concentrations at the Little Neck station (MAS2) on the lower Ipswich River, about 0.5 km from its terminus in Plum Island Sound, correlates well (r^2=0.80) with those at our station 1 at the mouth of the Sound itself off Steep Hill (Fig. 3.12). This is not surprising since most of the freshwater flow leaving Plum Island Sound at this point is derived from the Ipswich River. Apparently, fecal coliforms concentrations above about 150 cfu per 100 ml in the Ipswich River at Little Neck are required to elevate fecal concentrations at the mouth of the Sound itself above baseline levels.

Fig. 3.12. Influence of Ipswich River on fecal coliform concentrations at the mouth of Plum Island Sound. Low tide samples only.



3.354. Effect of tidal range on fecal coliform concentrations

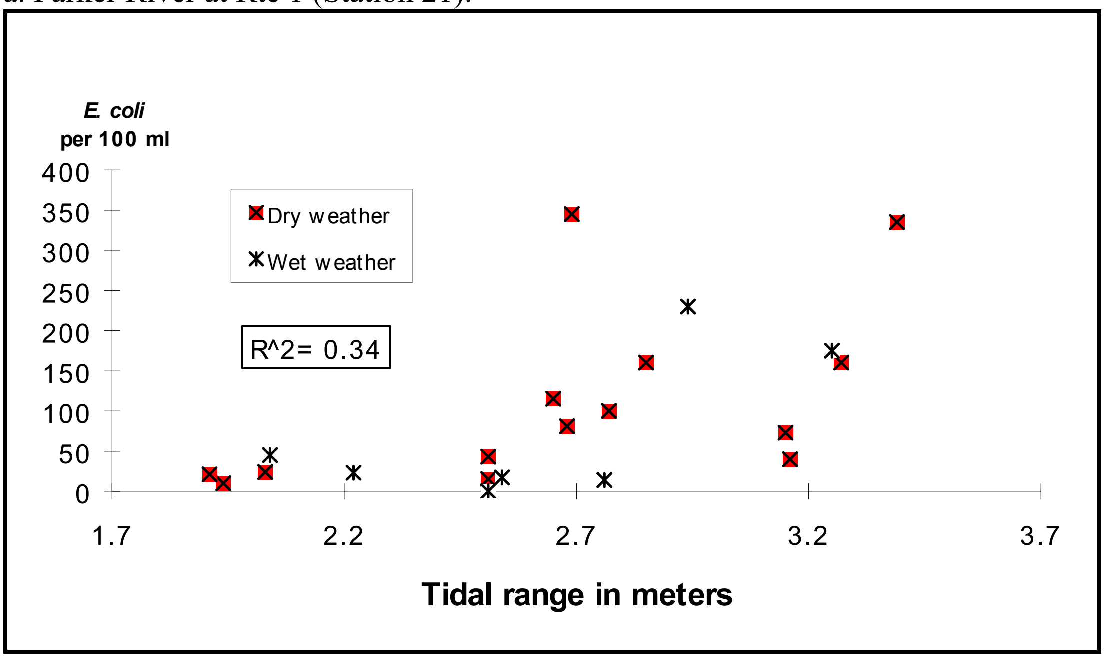
Vorsmarty and Loder (1994) described a relationship between nitrogen concentrations in the estuarine part of the Parker River and tidal range during the spring and neap tide cycle. They found that ammonia and nitrate concentrations in marsh creeks were higher during neap tide periods than spring tides. They concluded that when the marsh surface is flooded during a spring tide, the marsh acts as a sink for inorganic nitrogen due to plant uptake and denitrification processes. At neap tides, water remains within the salt marsh creeks and channels, and these processes do not occur, hence nitrogen concentrations are higher in the water.

Massachusetts Audubon carried out a similar analysis on stations in the estuarine part of the Parker River using fecal coliform bacteria rather than nitrogen. Concentrations of fecal coliforms on a sampling day were correlated with the tidal range on that day, estimated from NOAA tide charts for Plum Island Sound. At three of the four stations, concentrations of fecal coliform bacteria increased during periods when the tidal range was relatively high (Fig. 3.13). For stations MAS15 and MAS21, this analysis was repeated for wet and dry weather events separately (Fig. 3.13a-b). MAS15, which is near the mouth of the Parker River, was the one station where tidal range was not correlated with fecal coliform concentrations (Fig. 3.13b). At MAS21, approximately 2 km upstream, tidal range directly correlated with fecal coliform concentrations during both wet and dry weather events (Fig. 3.13a).

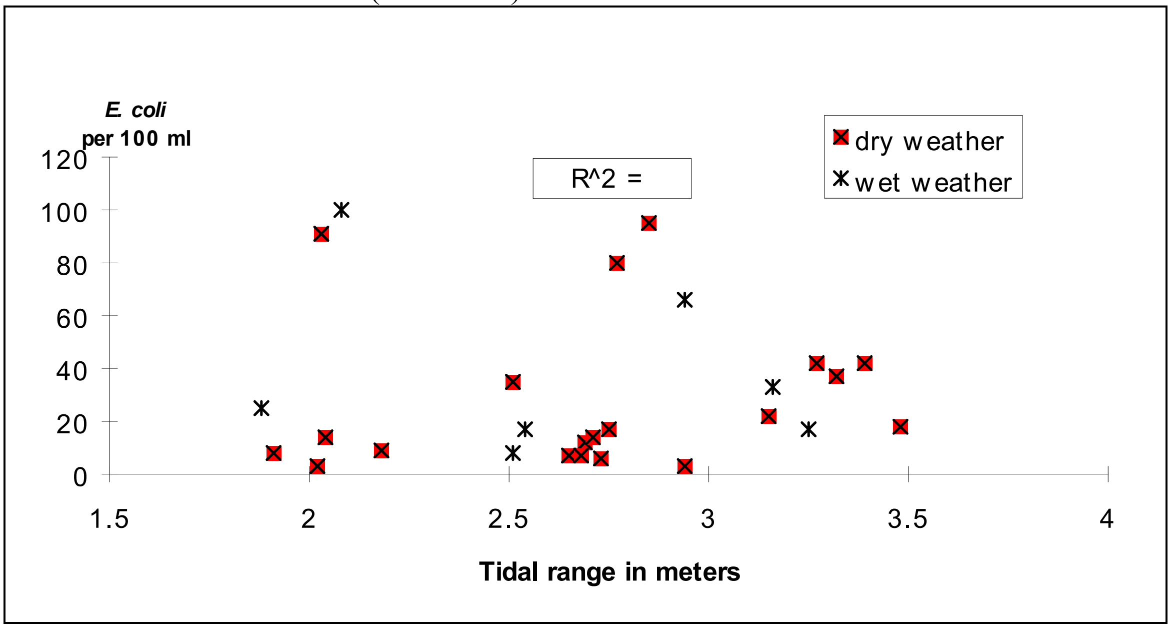
The increase in fecal coliform concentrations with increasing tidal range also occurred at the stations located at the lower ends of the Little and Mill Rivers (Figs. 3.13c-d). These stations are also upstream of station 15. One possible explanation of why the relationship occurred at stations upstream of station 15, but not at station 15 itself is that the relative volume of water to marsh surface area is much less at the three upstream stations, thus they would be subjected to greater impacts from processes occurring on the marsh surface when it is flooded.

Fig. 3.13. Fecal coliforms vs tidal range. Low tide samples.

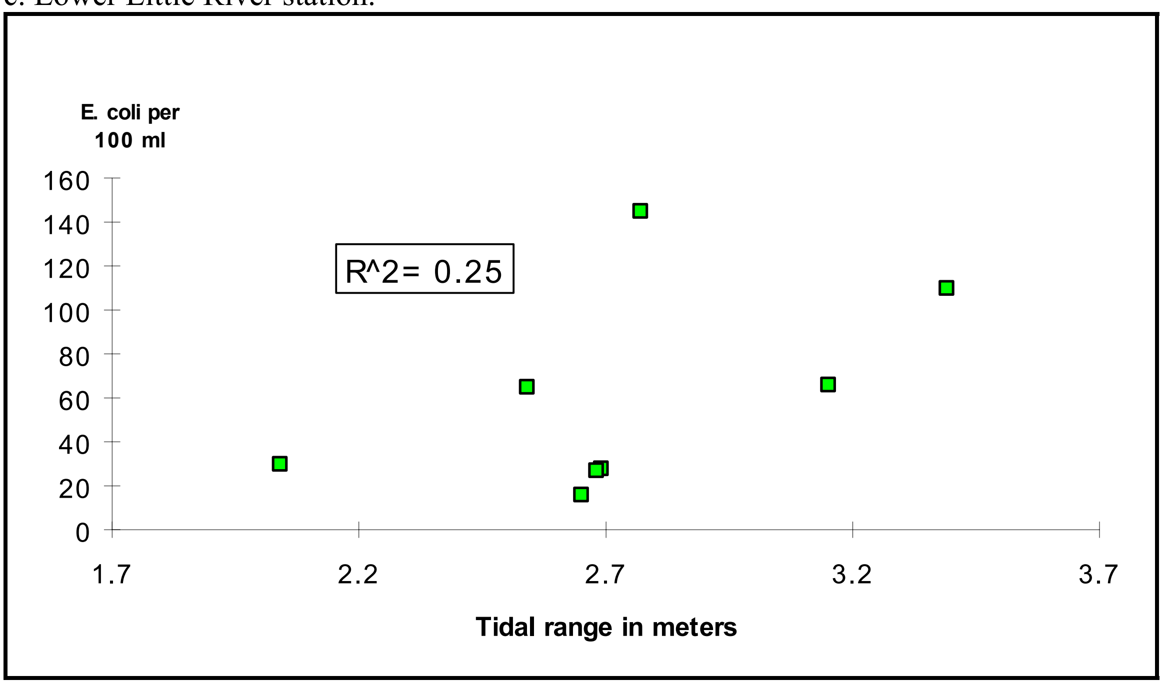
a. Parker River at Rte 1 (Station 21).



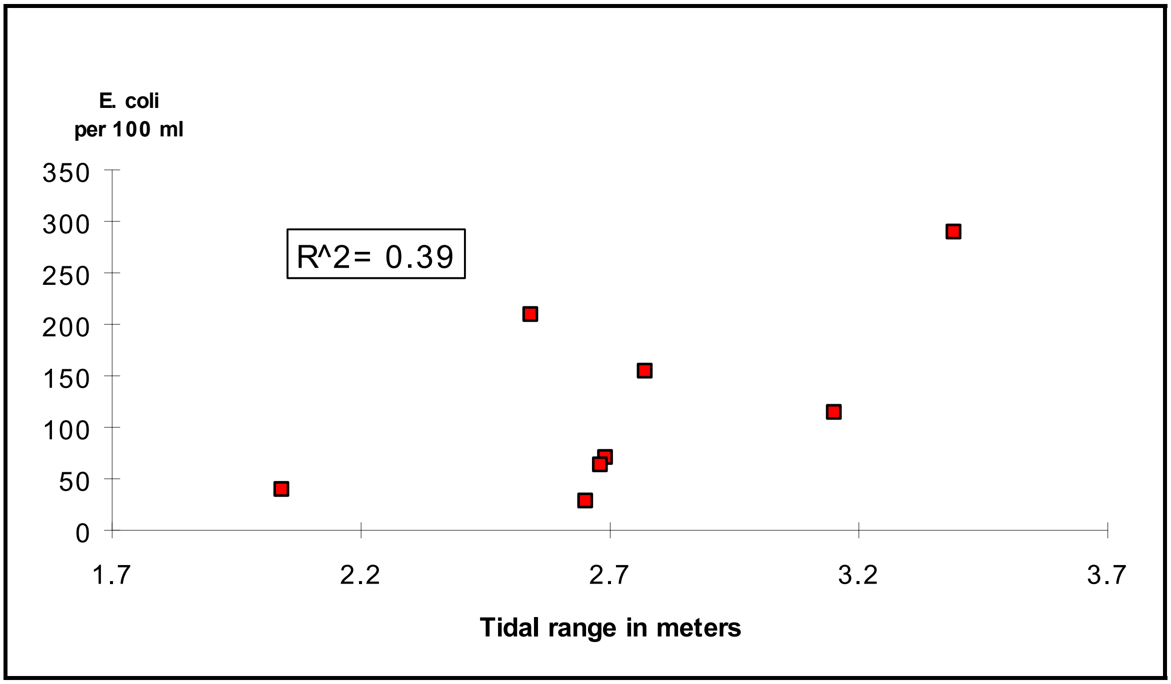
b. Parker River at Route 1A (Station 15).



c. Lower Little River station.



d. Lower Mill River station.

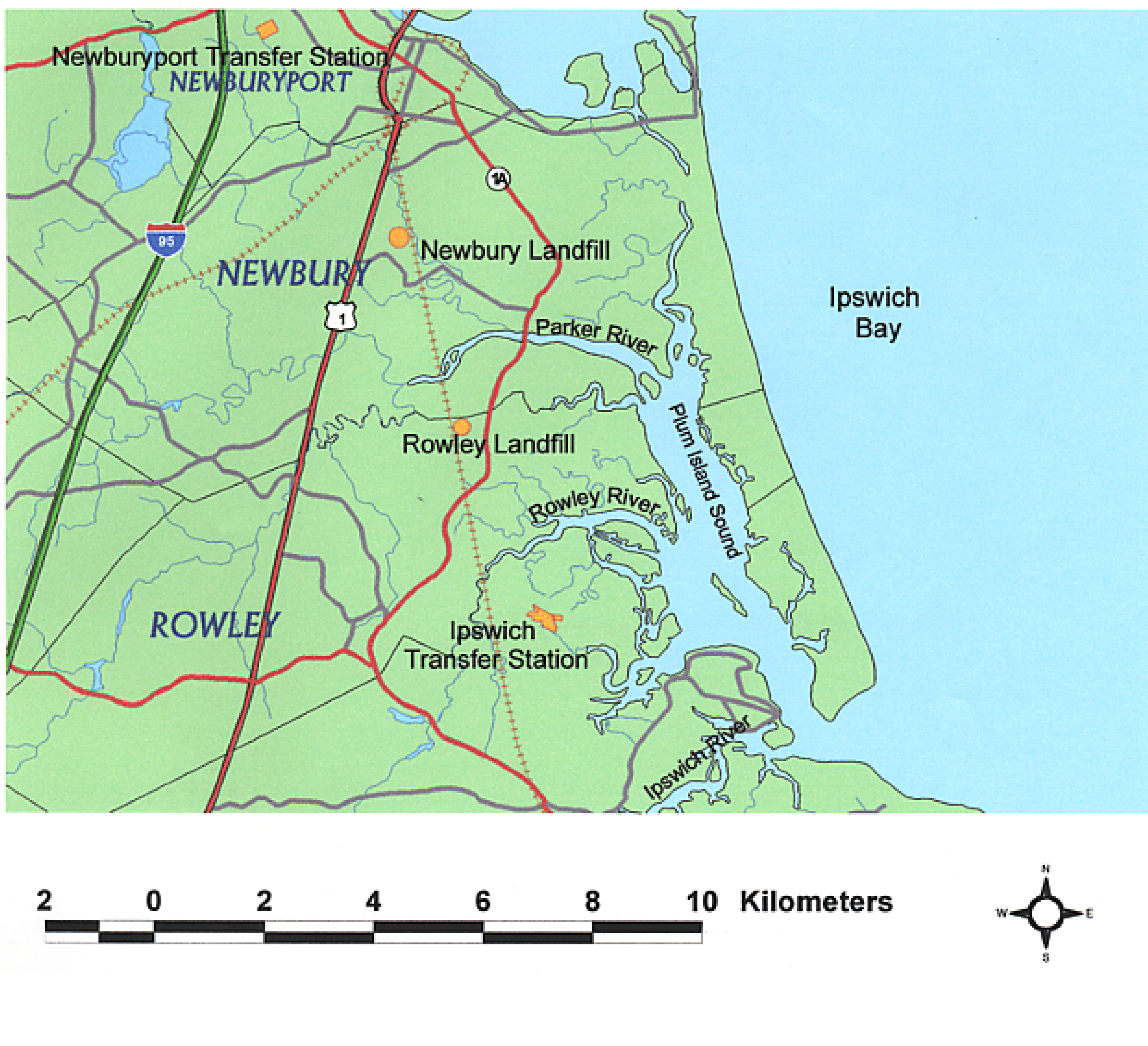


The analysis of the impact of tidal range on bacteria contrast with those reported by Vorsmarty and Loder for nitrogen. Bacteria behave differently from nitrogen when the marsh surface is flooded because the transport of bacteria is dependent primarily on physical processes whereas nitrogen transport is to a large extent mediated by biological processes. Thus fecal coliforms that are deposited in animal wastes on the marsh surface during the neap tide are apparently being mobilized from the marsh surface into the water column during spring high tides when the marsh is flooded. In contrast, nitrogen concentrations decrease as spring high tides exposes nitrogen to uptake processes on the marsh surface. This scenario suggests that a spring high tide is analogous to a stormwater event from a fecal coliform perspective.

3.4. Toxic Contaminants in the Plum Island Sound Region

The Parker River/Plum Island Sound Estuary, although relatively pristine, is not free of some contamination from metals, inorganics, volatile organic compounds, and total dissolved solids. Sources of these pollutants include the landfills (three of which are within the estuary and are perched on the edge of the salt marsh), private industries, marinas, junkyards and underground storage tanks (Figure 3.14). The degree of pollution from these sources is not completely known nor is the effect on the estuary biota. Data exist for one marina, two landfills and an abandoned plating industry.

Fig. 3.14. Location of landfills in the Plum Island Sound Region



3.41. Landfills

3.411. Ipswich

The Ipswich Transfer Station, located on Town Farm Road, is a closed and capped facility. The landfill, although capped, sits on the edge of the marsh presumably on portions of former salt marsh. It is located adjacent to Paine Creek, which flows into Plum Island Sound through the Eagle Hill River. Currently the former landfill is used as a transfer station for recyclables. The landfill was closed prior to monitoring requirements so little data exist on groundwater and adjacent water quality.

3.412. Rowley

The Rowley landfill, located off Old Rowley Road near Mud Creek, opened in the late 1950's and closed in 1992. Upon preparation for closure, a site assessment was preformed in 1990 for the Department of Environmental Protection (DEP).

The landfill is sited upon a moraine that is bounded by fresh and salt marsh, wetlands that are designated as an Area of Critical Environmental Concern. Six monitoring wells were installed in 1992 and soil samples were taken and sampled. The test results found that the well sites were devoid of harmful toxins with the exception of measurable levels of Dichlorodiphenyltrichloroethane (ddt) and heptochlor. Other compounds detected were arsenic, magnesium and lead. These compound levels exceeded the maximum contaminant level for safe drinking water. Due to relatively low levels of analytes detected, the engineering firm that prepared the report determined that the levels were not of concern and future analysis was deemed unnecessary. The landfill was slated to be capped in 1999 and under a consent order from DEP and was done so in that year.

3.413. Newbury

The Newbury Landfill, located off Boston Road adjacent to the Little River, has had a battery of environmental assessment tests taken in association with the transfer of the landfill from a non-mined landfill to a mined one. Landfill mining in Newbury started in the early 1990's and is a relatively novel approach to waste management; as a result the DEP has kept close tabs on the environmental effects.

A series of monitoring wells and surface sampling points were established to measure water quality. The results of these tests indicate that volatile organic compounds were not detected in 1989. The 1989 survey, which included two rounds of testing, indicated that metals (chromium, zinc and nickel) were present in some of the wells but these levels were below the maximum contaminant level (MCL). In one well chromium was slightly above the MCL and a surface water sample found that cadmium slightly exceeded the MCL. Concentrations of total dissolved solvents, chloride and sulfate in some of the wells exceeded the MCLs. Iron and Manganese, typical in areas underlain by igneous bedrock, were also above the MCLs. Silver was detected in one well at twice the level allowed by the Environmental Protection Agency standards. Seven pesticides: (endosulfan sulfate, gamma-bhc, delta-bhc, heptachlor epoxide, endodulfan II, heptachlor and 4,4' DDT were detected in three monitoring wells. Some of these did not exceed the MCLs, while four of these pesticides do not have established MCLs (Clark Engineers and Associates, 1990).

In 1993, water quality tests found that chlorobenzene, acetone and carbon disulfide were also present in some of the monitoring wells. (NEET, 1993)

In 1994, Port Engineering found that nitrate levels were slightly elevated in two test wells, total dissolved solids exceeded the MCL 3 to 3.5 times. Chromium, manganese and lead levels exceeded the MCL, in all wells, as well as in the baseline well site, indicating that the contaminants may not be disseminating from the landfill. Chlorobenzene and arsenic were also present in two wells (Port Engineering, Sept 1994).

In 1995 and 1996 water quality tests indicated similar results as 1994, with the trend since the 1989 tests showing reduced levels of containments. During the December 1995 study mercury exceeded the MCL in three wells and sulfates for one well were 4 times the MCL (Port Engineering Associates, 1995).

Soil conditions indicated in the 1989 tests that lead concentrations exceeded the MCLs for two sample points, the cause of these levels is unknown (Clark Engineers and Associates, 1990). In 1995 soil samples indicated that none of the samples exceeded Massachusetts DEP allowable contaminate levels for soil reuse at lined landfills (NEET, 1995).

The conclusion of Clark Engineers and Associates in 1990 was that the concentrations of pollutants were relatively low, but capping was recommended to stop the migration of water through the landfill to reduce contaminant mobility (Clark and Engineers and Associates, 1990). Despite this recommendation the landfill has been mined since the 1990s. In 2000 violations to the landfill permit were discovered by DEP. The Attorney General issued a complaint against the Town of Newbury to Suffolk Superior Court and sought an interim order to rectify on-site violations. According to the interim order the town was required to hire a qualified independent environmental consultant to oversee the landfill operations. The Town of Newbury hired Camp, Dresser and McKee, Inc. to comply with the order and furnish interim reports. The first consultant report has not yet been issued as of March 2001.

3.414. Newburyport

The Newburyport landfill is located off Crow Lane in a region of freshwater marshes at the headwaters of the Little River. At the time of this report, the landfill was not capped. Ransom Environmental Engineering conducted an assessment report, for a private client, this report is not available to the public.

3.42. Industrial Contamination

Circle Refinishing, Inc., formally located on the Route One traffic circle in Newburyport and Newbury, operated an electroplating and metal finishing factory from 1968 to 1993. Wastewater was discharged from copper, nickel and chromium plating, the byproducts of this process included zinc, cyanide and various acids. The Newburyport Wastewater Treatment Plant processed these byproducts. On December 20, 1993 a fire consumed the factory, releasing hazardous materials, mostly via water used to extinguish the blaze, into the surrounding wetlands.

The site is perched on an expanse of freshwater and brackish wetlands that feed the nearby Little River, which is tidal up to, and just west of Route 1. An imminent hazard evaluation completed by a local environmental firm found that there was no risk to human health but that there was potential risk to the environment, especially to benthic organisms from the exposure to polluted sediments and from a contaminated vegetative mat layer. Surface water quality, as well as ground water was affected, especially water overlaying the effected sediments (Letter from Ransom Environmental Consultants, Inc. to DEP, 1995). An effort to contain the spread of contaminants was temporarily performed by restricting water flow by the use of an in-stream air bladder.

It was found that the effects of the fire and the release of contaminants were mitigated by dilution by the Little River. Water quality tests found that zinc and nickel were present within the Little River but they were below the acute and chronic criteria (Letter from Ransom Environmental Consultants, Inc. to DEP, 1995).

During the clean up of the site, 15 tons of cyanide-impacted soil were removed and transported to Quebec, Canada. As of March 2001, a full scale clean up and reuse of the site has not been completed. The site is classified by the DEP as a Tier 1-B, meaning that it may be cleaned up with oversight from a Licensed Site Professional under a permit from the DEP.

3.43. Sediment Quality

The Parker River Watershed Team performed sediment quality tests in 1994 for three sites in the estuary (Table 3.42). Sites were specifically chosen to determine if metals were present in the aquatic soils near Riverfront Marina on the Parker River, below the Newbury Landfill, on the Little River, and downstream of the Lord Timothy Dexter Industrial Park in Newburyport, on the Little River. For the most part the data shows that the metal concentrations were below levels that are determined to cause significant detrimental impacts to biota, although levels of arsenic and aluminum were high for two of the samples.

Table 3.42. Sediment Quality Data (mg/kg dry weight) from the Parker River Watershed Team, Mass (EOEA 1996).

Station	Hg	As	Cu	Cd	Al	Zn
Concentration of Contaminant where no adverse impacts would be expected	0.2	6	16	0.06	NA	120
Concentration of Contaminant where significant detrimental impacts would be expected	2	33	110	10	NA	820
Little River, Parker Street	<0.0002	10.6	12	<0.03	1.510	78
Little River, Below Landfill	<0.0002	49.3	33	<0.03	1.310	179
Parker River, Riverfront Marina	<0.0002	3.57	17	<0.03	7236	54

The detrimental effects of toxins present in low levels in the estuary are not specifically known, although some wetland species are known to bioaccumulate toxins.

3.5. Pollution and Its Effect on Marine Resources - A Thirty Year Perspective

3.51. Water quality of Plum Island Sound past and present

Roughly the same acreage of shellfish beds are classified as prohibited in the 1990s as when the DMF carried out their study in 1965. In 1965 this included 138 ha of moderately contaminated flats (7.3 % of the total acreage of productive clam flats) and 307 ha of grossly contaminated flats (16.3 % of the total). Jerome et al. (1968) noted that the harvest of soft shell clams has been restricted in the Ipswich River and its tributaries since 1928. They noted that the quantities of raw industrial and domestic sewage directly entering the Sound had been much reduced from the early 1900s when many small factories and mills discharged raw sewage into tributaries. They also expressed optimism that the impending sewering of the core area of Ipswich should result in further reductions in the amount of sewage entering the river and therefore improved water quality.

DMF presently classifies most of Plum Island Sound as conditionally approved for shellfishing depending on rainfall (see Tables 5.3 and 5.4 in Chapter 5). Bacterial counts for most of the Sound do not exceed the standard for clean shellfish beds during dry weather. The exceedences that occur during wet weather are not great, generally in the range of 14 to 100 *E. coli* per 100 ml, but are still above the standard.

The Minibay and ICPCC studies carried out in the early 1990s supported classification of the Ipswich River estuary as prohibited for shellfishing due to high fecal coliform counts. Since that time, the Town of Ipswich has been active in addressing pollution problems; this has enabled the town to open some clam flats in the Ipswich River estuary (see Chapter 5).

The Parker River above Route 1A has recently been closed for shellfishing by DMF due to fecal coliform contamination. Fecal coliform concentrations as measured in the Minibay Project averaged between 38-176 per 100 ml in this newly closed region.

It is interesting to note how the major water quality issues, as reflected in the types of sampling carried out, changed from the 1960s to the 1990s. A central part of the report by Jerome et al. (1968) on the Parker River-Plum Island Sound Estuary (and in the other estuarine reports in the monograph series as well) was pesticide analysis. Jerome et al. reported detectable levels of DDT residues in some, but not all, samples of soft shell clams and white perch collected within the estuary. Levels were substantially lower than in finfish collected from the nearby Merrimack River estuary. With the banning of chlorinated hydrocarbons in the 1970s, DDT and related compounds never emerged as an issue in the Minibay Project. Instead, the major focus, driven to a large extent by both local and statewide expressions of concern, was on fecal coliform contamination and its impact on shellfish harvesting. Jerome et al. also raised fecal coliform contamination as an important issue, but no actual data were presented.

Stormwater runoff, an issue that receives much more attention now than it did thirty years ago, is considered a significant problem for the Sound as it is for most of the Massachusetts coast. Unfortunately, stormwater runoff is still very difficult to control. The rainfall closures for the entire Sound were not in effect in 1968, but this is likely the result of better monitoring now than in the past.

Some population growth and development has occurred in the region over the past 30 years, however unlike Cape Cod where shorelines have been the focus of intensive new housing construction, most new subdivisions in the Plum Island Sound region are located some distance from the Sound itself. Thus there is a better chance that the Sound has been somewhat buffered from pollutants generated by new developments. In sum, there is no hard evidence that the water quality within the Sound has deteriorated at least over the past 30 years despite recent recognition of the problem represented by stormwater.

3.52. Landscape factors that effect fecal coliform concentrations

Wetlands and the ponding of water behind dams likely attenuate bacteria before they enter the estuary. During dry weather Ipswich River water flowing over the Sylvania Dam is relatively low in fecal coliforms despite major sources upstream, i.e. the Miles River and Kimball Brook. Bacteria traveling downstream in the river are likely settling out when they reach the low flows behind the dam. In addition bacteria from farther upstream in the Ipswich may be trapped within the extensive wetlands system upstream in Topsfield and Wenham. The Woods Hole LTER project noted that nitrogen concentrations flowing over the Sylvania Dam were extremely low compared to those in the Ipswich upstream of the extensive wetlands (C. Hopkinson, unpublished results). The same effect on fecal coliform concentrations has been noted on two small artificially created ponds behind dams in the Mill River (Leahy and Buchsbaum, 1998).

This beneficial effect of ponding on water quality is subverted during wet weather events. Heavy rains resuspend the bacteria, causing them to reenter the water column and flow over dams. Once again, this points to the difficulty of controlling stormwater pollution.

3.53. A summary of suspected pollution sources to the Sound

The estuarine part of the Ipswich River is the major source of fecal coliforms to the region, contributing 70% and 52% of the total fecal coliform load during dry and wet weather respectively. The flushing study indicates that most Ipswich River water is quickly flushed out of the Sound and therefore does not affect the central and northern sections of the Sound. Nonetheless, some potential clam flats in the Ipswich River estuary are still closed due to contamination that enters the Ipswich River downstream from the Sylvania Dam. Recent management efforts of the town have focused on remediating sources of contaminants on this relatively well-defined part of the Ipswich River, such as upgrading the wastewater treatment facility, discouraging feeding of water birds, and searching for hidden direct discharge pipes in the downtown area. At the time of this writing these have already yielded benefits in terms of opening up some shellfish beds.

The Little River, a tributary of the Parker, is the major source of fecal coliforms to the upper part of Plum Island Sound. This conclusion is based on loading calculations from the Minibay Project and on the strong correlation between fecal coliform concentrations in the Little River and those near the mouth of the Parker.

Despite contributing a smaller bacterial load to the Sound than the Little River, the Mill River contained two particularly "hot spots". These were a small stream flowing into the Mill from the Governor Dummer Academy (GDA) and Ox Pasture Brook in the center of Rowley. Governor Dummer Academy has recently upgraded their treatment plant under the guidance of DEP. Water quality in Ox Pasture Brook may be affected by an increased number of septic system upgrades, although there is no coordinated management plan to improve water quality in the brook.

Based on the flushing study, the Merrimack River likely has very little influence on the Sound itself since little Merrimack River water routinely reaches the Sound. The dye study carried out by the FDA and DMF indicated that Merrimack River water is diluted about 600:1 by the time it reaches the upper boundary of Plum Island Sound at its junction with the Plum Island River. Thus fecal coliform concentrations in the Merrimack of 900 per 100 ml will be diluted to roughly the shellfish standard by the time it reaches the Sound.

Hellcat Swamp and Stage Island in the Parker River National Wildlife Refuge occasionally have elevated levels of fecal coliforms that may affect their immediate surroundings. Due to the minuscule flow from these sources compared to the Ipswich and Parker Rivers, the overall impact from wildlife from the Refuge on the water quality in the Sound is negligible.